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Shipboard Implementation and Concept of Operations for Automatic Link Establishment

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ADMINISTRATIVE INFORMATION

This task was carried out by personnel in the Communications Technology Branch (Code 824) of the Naval Command, Control and Ocean Surveillance Center (NCCOSC), Research, Development, Test and Evaluation Division (RD&TE Division). Sponsorship was provided by the Space and Naval Warfare Systems Command, under program element OMN, accession number ICCG9800.

Released by
J. B. Rhode, Head
Communication Technology
and Systems Branch

Under authority of
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Communications Systems
Engineering and Integration
Division

PK

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1.0 BACKGROUND

Historically, the establishment and maintenance of high-frequency (HF) communication links has been viewed as "black magic." For shipboard HF communications, attempts to understand the "black magic" have been confused by antenna radiation patterns, self-generated noise/interference, frequency management, and a lack of knowledge about the HF channel.

In the interest of improved operation of and interoperability between HF systems of various services, MIL-STD-188-141A (reference 1) was published on 15 September 1988. Federal Standard 1045 (reference 2, included as appendix A of reference 1) presents the Automatic Link Establishment (ALE) System. This system is designed to aid the operator in eliminating the confusion described above and to allow quick establishment of reliable circuits. However, existing shipboard communication systems (except on LHD 1 Class) can not fully implement the system or technique (reference 1, appendix A).

Successful testing of the ALE system was accomplished between the USS *Tarawa* (LHA 1) and various shore stations during the period of April 1992 – November 1992 (reference 3). A significant amount of testing between several fixed site locations has been coordinated by The MITRE Corporation.

If high-frequency communications circuits/networks are to play a viable role in the Copernicus architecture of the future, techniques must be available to assist the operator (or computer) in establishing reliable circuits/networks quickly.

2.0 SCOPE

The scope of the task reported here was to develop implementation techniques and concepts of operation for using HF ALE techniques, as presented in MIL-STD-188-141A, with shipboard systems designed to quickly establish good, reliable ship/beach and ship/ship communications (links and networks) for effective use by any control method/system (e.g., Communication Support System [CSS], Communication Monitoring Control System [CMCS], etc.) .

3.0 PRESENT SHIPBOARD EQUIPMENT SUITES

The first step in developing implementation techniques for using ALE on a ship is to review the ship's radio frequency (RF) equipment. The RF equipment will have an impact on the scanning of receive frequencies (how many; can it be done; etc.), and the system's ability to answer a call in a timely fashion. These are important operational rules for ALE.

Figures 1 and 2 show the two basic shipboard RF equipment architectures—narrowband and broadband. For narrowband, there are four different major configurations with several variations; although, at this time, only one broadband system exists in the fleet (table 1). Figure 1 is the generic block diagram of narrowband architectures for all but LHA class ships. The receive systems on the LHA ships do not have a multicoupler; instead they combine at the receiver antenna inputs and use an integral preselector.

Table 1. Shipboard HF RF equipment suites.

I. Narrowband

A. Classic
- AN/URT-23 TRANSMITTER
- R-1051 RECEIVER
- AN/SRA-56,7,8 XMT MULTICOUPLERS
- AN/SRA-49 RCV MULTICOUPLER
- AN/URA-38 XMT ANTENNA COUPLER
- CU-2113 CARTS FOR RCVG
- MANUAL RF SWITCHING MATRICES

A1. CG 54 and UP
SAME AS A EXCEPT:
- R-2368/URR-79 REPLACES R-1051 RECEIVER

A2. DDG 51 CLASS
SAME AS A EXCEPT:
- AN/URA-38 XMT ANTENNA COUPLER NOT USED

A3. FFG 7 CLASS
SAME AS A EXCEPT:
- AN/SRA-57,8 XMT MULTICOUPLERS NOT USED

B. DD 963/DDG 993 CLASSES
- T-1322/AM-6675(AM-3924 Mod.) TRANSMITTER
- R-1903 RECEIVER
- OE-219/232/231 (SRA-34 Mod.) XMT MULTICOUPLERS
- AN/URA-38 XMT ANTENNA COUPLER
- OA-8796 (SRA-49 Mod.) RCV MULTICOUPLER
- CU-2096 DIPLEXER FOR RCVG
- NORMAL-THRU RF RCV SWITCHING MATRIX
- SA-1070 RF XMT SWITCH MATRIX

B1. CG 47—CG 53
SAME AS B EXCEPT:
- CU-2096 REPLACED WITH CU-2113

Table 1. Shipboard HF RF equipment suites (continued).

C. LHA CLASS
- AN/URC-81 TRANSCEIVER
- AN/URT-38 TRANSMITTER
- AN/SRC-23 TRANSCEIVER (RT-1036/AM-3799)(LINK 11)
- AN/URR-67 RECEIVER
- CU-2035/1780/1781(SRA-34 MOD.) XMT MULTICOUPLER
- CU-1901 RCVR COUPLER
- AN/SRA-51 RCV ANTENNA
- SA-1865/UR XMT SWITCHING MATRIX (MODIFIED SA-1070)

D. CV, CVN, CG, CGN CLASSES (OTHER THAN ABOVE)
- AN/SRC-16 TRANSCEIVER (LINK 11)
- AN/URT-23 TRANSMITTER
- R-1051 RECEIVER
- CU-1169/SRC-34 XMT MULTICOUPLER
- AN/SRA-57 XMT MULTICOUPLER
- CU-1170/SRA-16 XMT MULTICOUPLER
- AN/URA-38 XMT ANTENNA COUPLER
- AN/SRA-49 RCV MULTICOUPLER
- CU-2113 CARTS FOR RCVG
- SA-1070 RF XMT SWITCH MATRIX

D1. Later CVN Class

SAME AS D EXCEPT:
- AN/SRC-23 REPLACES AN/SRC-16
- AN/SRA-58 REPLACES CU-1170/SRA-16
- AN/SRA-38,-39,-40 REPLACES AN/SRA-49

II. BROADBAND

A. LHD CLASS
- AN/URC-109 TRANSMITTER/RECEIVER SYSTEM

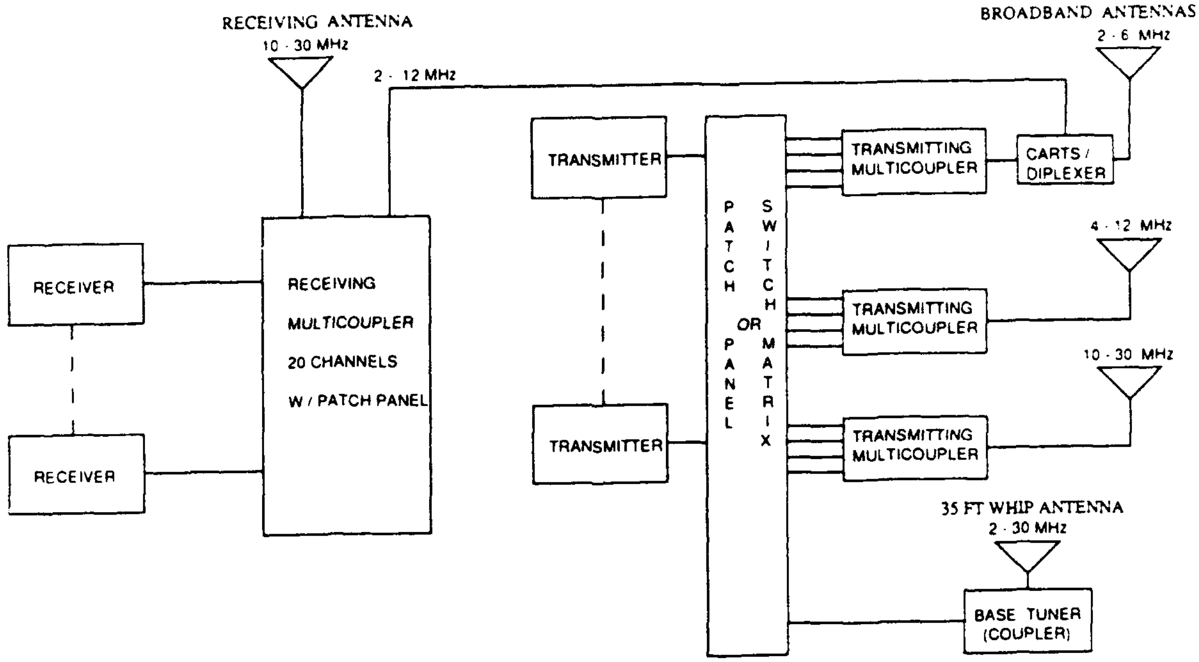

Figure 1. Narrowband HF architecture.

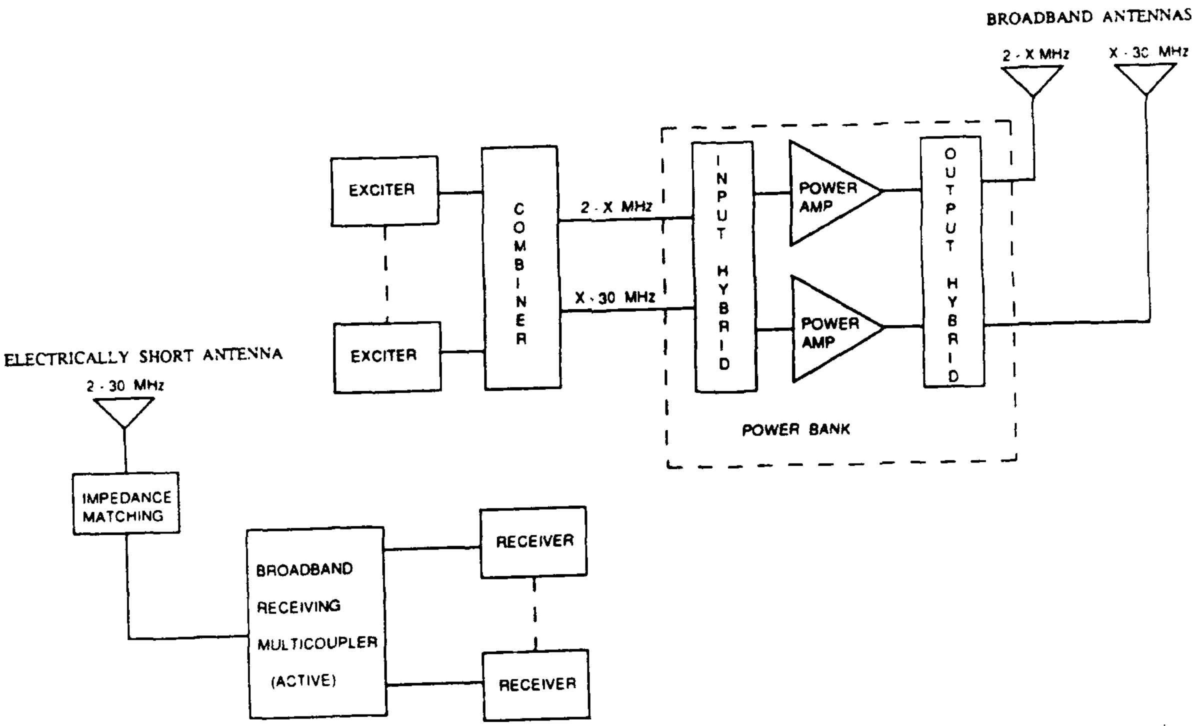

Figure 2. Broadband HF architecture.

4.0 HIGH-FREQUENCY CIRCUITS

High-frequency shipboard communication services are provided by setting up the number of different circuit configurations required to meet the overall communication requirements. The number of circuits will depend on the operational scenario. Table 2 (taken from reference 4) lists the various circuit configurations that ALE must support. N and P circuit configurations are not listed because the future role of HF services (figure 3) does not include long-haul ship-to-shore communications.

Table 2. Shipboard HF circuit configurations.

CIRCUIT TYPE	CHARACTERISTICS
B/C	Single Channel Teletypewriter (AFTS), Secure, Simplex/Duplex
D/G	Single Channel Teletypewriter (RFCS), Secure, Simplex/Duplex
K/M	Single Channel Teletypewriter (RFCS), Secure, Half Duplex (Receive)
S	Narrowband Voice, Secure, Simplex/Duplex
V/VV	Single Channel Teletypewriter (RFCS), Nonsecure, Duplex/Half Duplex/Simplex
Y	Narrowband Voice, Nonsecure, Simplex/Duplex
Z/ZZ	Single Channel Facsimile, Secure, Duplex/Half Duplex/Simplex
Link 11	Digital Data, Secure, Simplex
Link 14	Single Channel Teletypewriter, Secure, Half Duplex (Transmit or Receive)

The definitions of simplex, half-duplex, and duplex (full duplex) are the following as defined in DNC-5.

> Simplex: Type of operation that provides a single channel or frequency on which information can be exchanged. All stations on the circuit are capable of transmitting and receiving information, but not simultaneously.
>
> Half-duplex: Type of operation that provides unidirectional electrical communications between stations. Technical arrangements may permit operation in either direction, but not simultaneously. Therefore, this term is qualified by one of the following suffixes: S/O (send only), R/O (receive only), S/R (send or receive).
>
> Duplex (full duplex): Type of operation that provides two channels or frequencies linking two different stations, allowing the simultaneous exchange of information.

The ALE technique as presented in MIL-STD-188-141A, appendix A (reference 1) can be applied to all of the circuits shown in table 2, with the exception of Link 11 because of its networking technique. Later Federal Standards, which could become part of a new MIL-STD-188-141( ), may be applicable to Link 11.

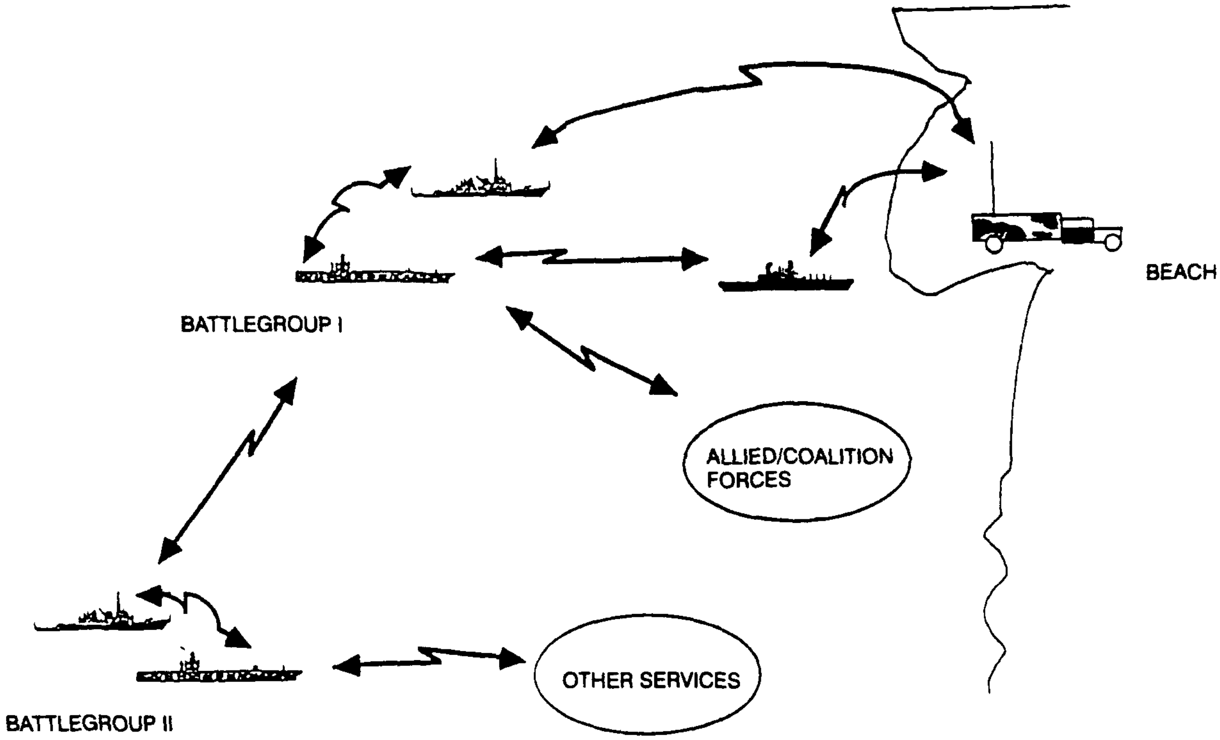

Figure 3. Future role of HF services.

5.0 SYSTEM IMPLEMENTATION

Because of the cost involved, implementation of the HF ALE capability into the existing shipboard communication systems within each ship and within ships of a battlegroup, can only happen in an evolutionary fashion. Thus, each ship's capability could change with time as technology and funds are available. Also, a battlegroup may consist of ships at different points in the evolution of ALE from a useful technique (supporting some of the shipboard communication services) to a fully capable one (performing all the options of the MIL-STD-188-141A, appendix A, for any applicable communication service). However, this standard does not provide for all the requirements necessary for all Navy systems; Federal Standards 1046, 1047, 1048, and 1049 must become part of future systems.

Implementation of HF ALE could involve any of the options below:

1. Adding an automatic transceiver, ALE modem/controller (ALEM/C), and operator's terminal to the existing shipboard system by using an existing 35-foot whip antenna (configuration used during the testing as reported in reference 3)
2. Integrating an ALEM/C and operator's terminal into the existing HF system by using manually tuned equipments
3. Implementing a broadband receiving subsystem with scanning receiver(s), ALEM/C(s), and operator's terminal(s)
4. Adding a broadband transmitting subsystem to the above #3.

5.1 OPTION 1: AUTOMATIC ALE TRANSCEIVER SUBSYSTEM

This option (figure 4), which involves the addition of an automatic ALE transceiver subsystem, including ALEM/C and operator's terminal, to the existing ship system, includes an automatic antenna coupler with an existing whip antenna. This subsystem could be integrated into the HF system through a switch matrix for use by any communication service or operate as a stand-alone capability to provide guidance on the available HF frequencies.

ADVANTAGES

1. Provides a fully compatible ALE capability
2. Has minimal impact on the existing HF system
3. Can be integrated into a HF system and provide the ALE capability for one communication service

DISADVANTAGES

1. When providing frequency selection guidance to other subsystems, the differences in antenna patterns may negate the selection.
2. Not a typical shipboard installation and could result in electromagnetic interference (EMI) to the receive side of a circuit.
3. This introduces new equipment other than the ALEM/C and operator's terminal into the Navy inventory
4. Antenna patterns are inferior to those of the broadband antennas.

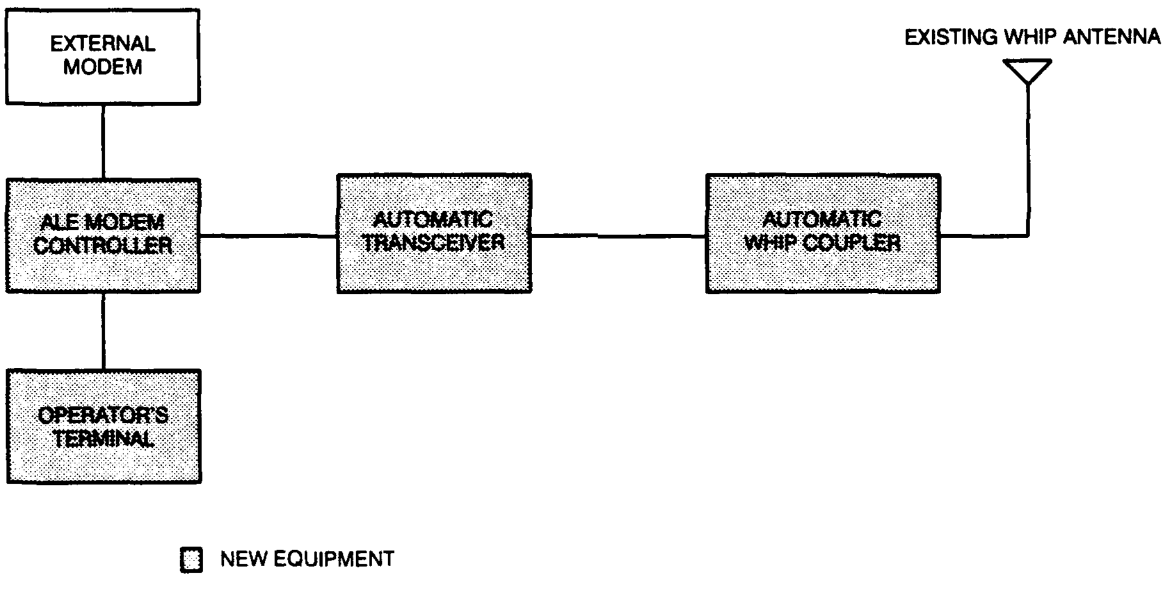

Figure 4. Option 1: automatic ALE transceiver.

5.2 OPTION 2: ALE MODEM/CONTROLLER

This option does not follow on from option 1 above, but is a different starting point in the evolution of ALE into the shipboard HF system. An ALEM/C and operator's terminal would be added to any of the existing shipboard systems (figure 5). The option would be integrated such that it could be switched into any subsystem to provide an ALE capability for any communication service. Multiple ALEM/Cs could be installed.

ADVANTAGES

1. Provides a very limited ALE capability for a particular communication service
2. Has minimal impact on existing HF system
3. Uses same antennas for ALE and communication service
4. Has minimum cost for an ALE capability

DISADVANTAGES

1. Scan sets and frequencies within a scan set are limited to one for the narrowband HF systems.
2. Several possible frequencies for a communication service or services take considerable time to evaluate.

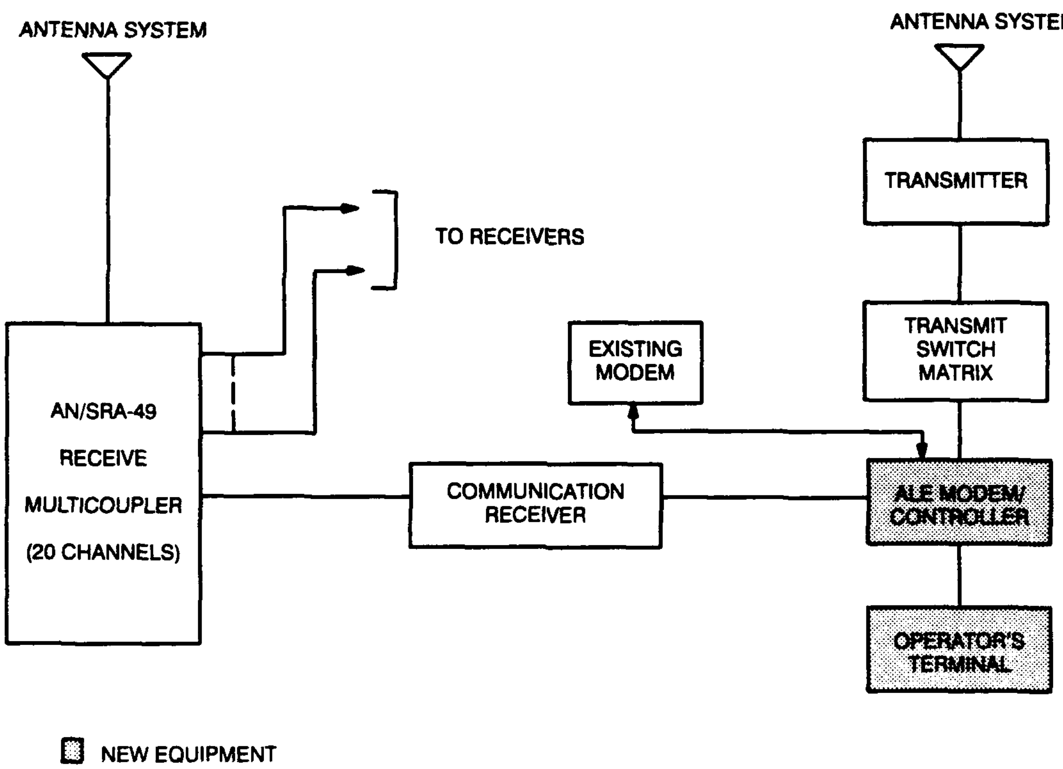

Figure 5. Option 2: ALE modem/controller.

5.3 OPTION 3: BROADBAND RECEIVING SUBSYSTEM

This option could be either a starting point in evolving ALE into the fleet or could follow on from option 2. Implementation of this option could be accomplished in the following ways: (1) Provide access to the 20 channels of the AN/SRA-49 receiving multicoupler for a scanning receiver while providing signals to the normal communication receivers; (2) Place a broadband receiving subsystem (like that used by the AN/URC-109) on the ships in place of, or in addition to, the existing receiving subsystem. The ALEM/C and operator's terminal would interface with the scanning receiver and a manual transmit subsystem. Various transmit subsystems could be connected to the ALEM/C to support different communication services. Different methods of implementation are shown in figures 6, 7, and 8.

ADVANTAGES

1. Provides a limited compatible ALE capability for a particular communication service
2. Scans several frequencies listening for calls
3. Uses same antennas for ALE and communication service
4. Eliminates any frequency constraints when using second option 3D (figure 9)

DISADVANTAGES

1. Number and distribution of frequencies limited by the AN/SRA-49 (for options 3A, 3B, and 3C)
2. Slow response to call unless transmit subsystem is pretuned
3. Potential EMI problems with option 3D on small platforms

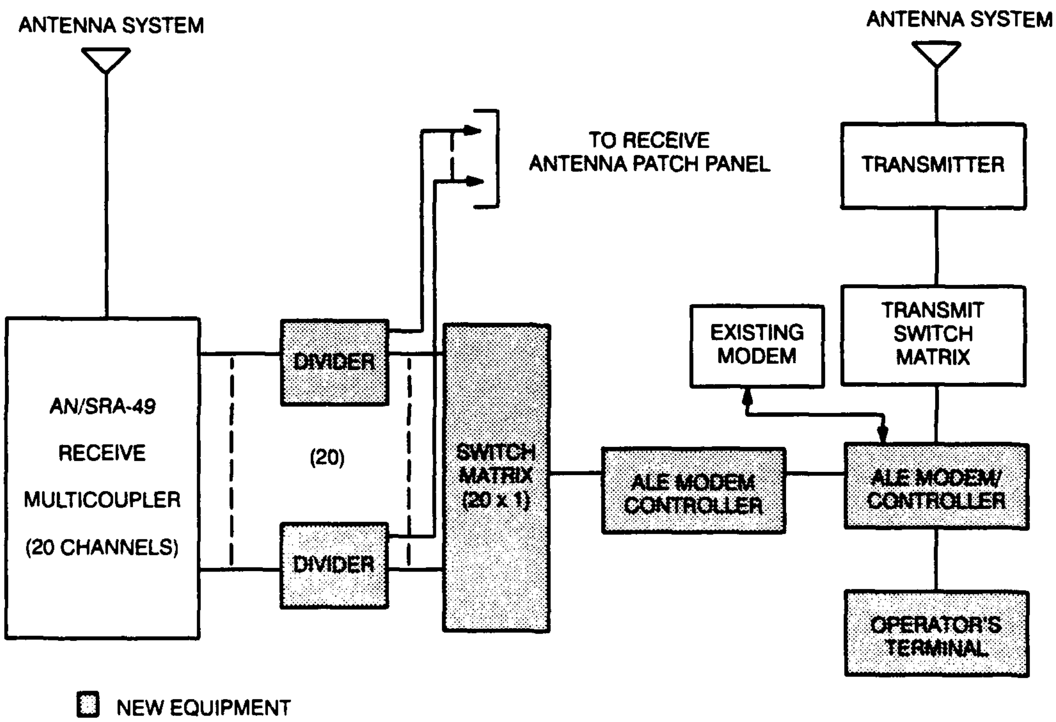

Figure 6. Option 3A: Broadband receiving subsystem.

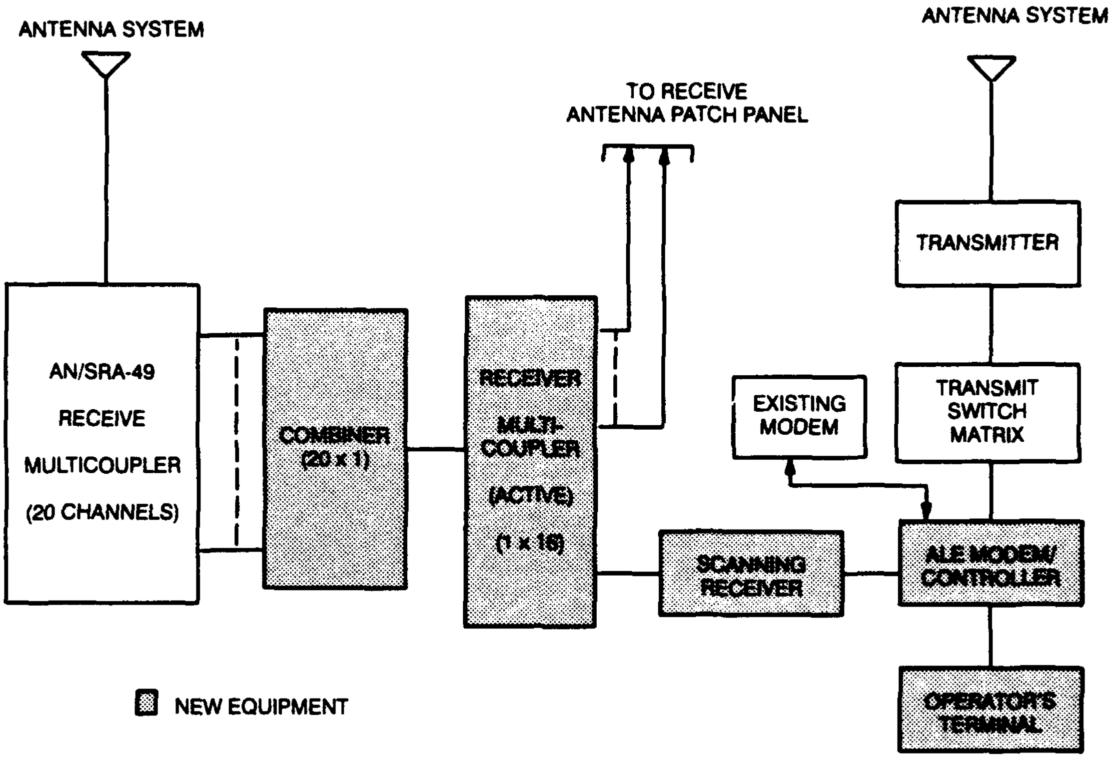

Figure 7. Option 3B: Broadband receiving subsystem.

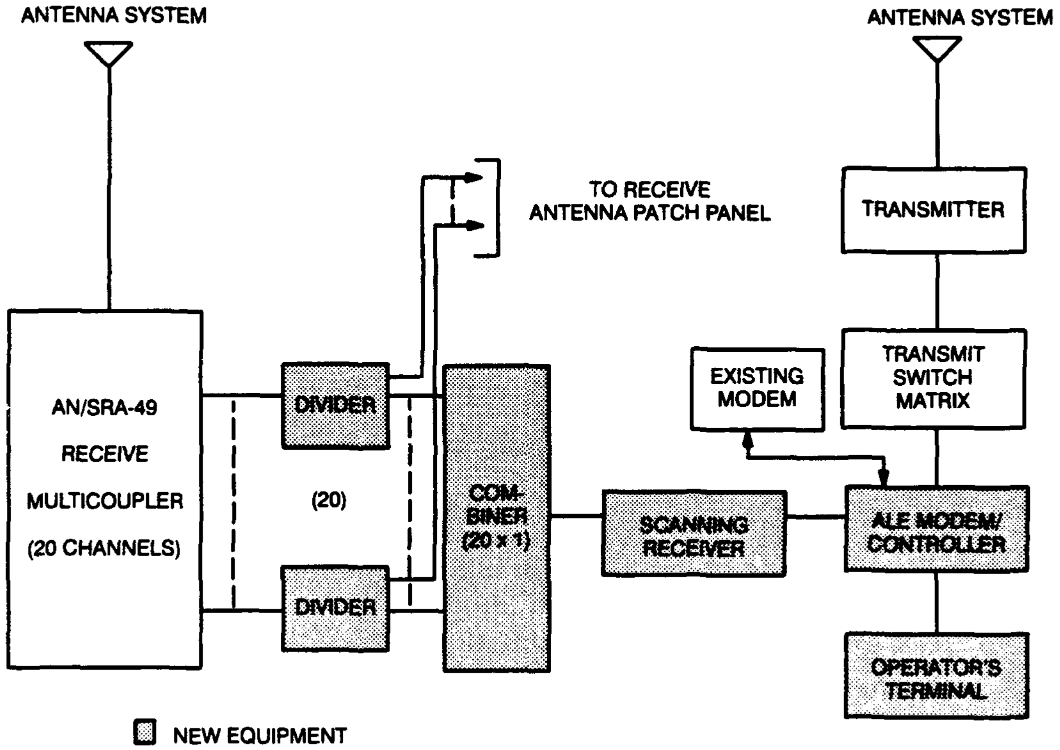

Figure 8. Option 3C: Broadband receiving subsystem.

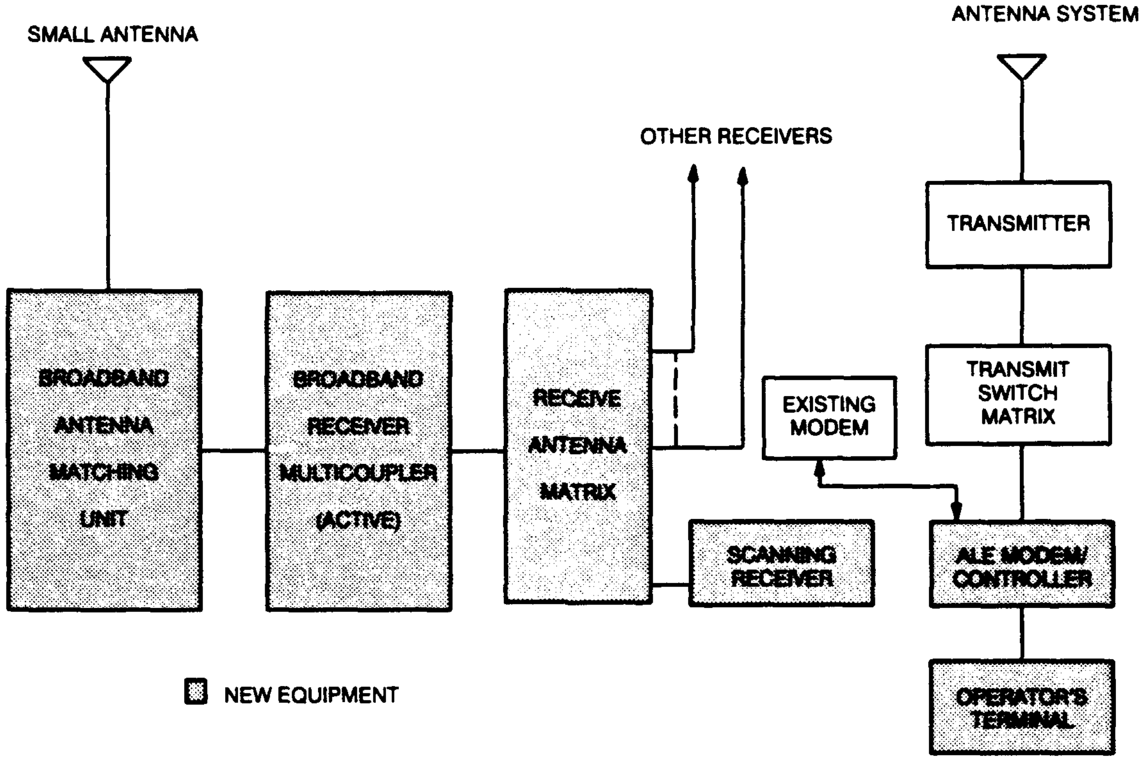

Figure 9. Option 3D: Broadband receiving subsystem.

5.4 OPTION 4: BROADBAND SYSTEM

This option (figure 10) would add a broadband transmitting subsystem to option 3 above. Adding this option to option 3D (figure 9) would be preferable. This results in a fully broadband system that is not constrained by any mechanically tuned devices. With the addition of an ALEM/C and operator's terminal, one would have a full ALE capability limited only by the ALEM/C .

ADVANTAGE

1. Fully compatible ALE capability

DISADVANTAGES

1. Expensive to do as evolutionary approach for existing ships
2. Potential for EMI problems if improperly designed or operated

5.5 QUANTITY OF ALEM/CS

The quantity of ALEM/Cs and operator's terminals per ship should be determined by the number of different receiving antenna subsystems used. Operational rule 1 (table 3) states that it is critical that the ALEM/C is always listening. Because of antenna pattern differences and frequency coverage, each antenna subsystem should be covered simultaneously. Since the ALEM/C does not monitor the communication service performance, there is no need to provide one for each service. Shared use is the recommended implementation approach. One additional ALEM/C should be provided for backup.

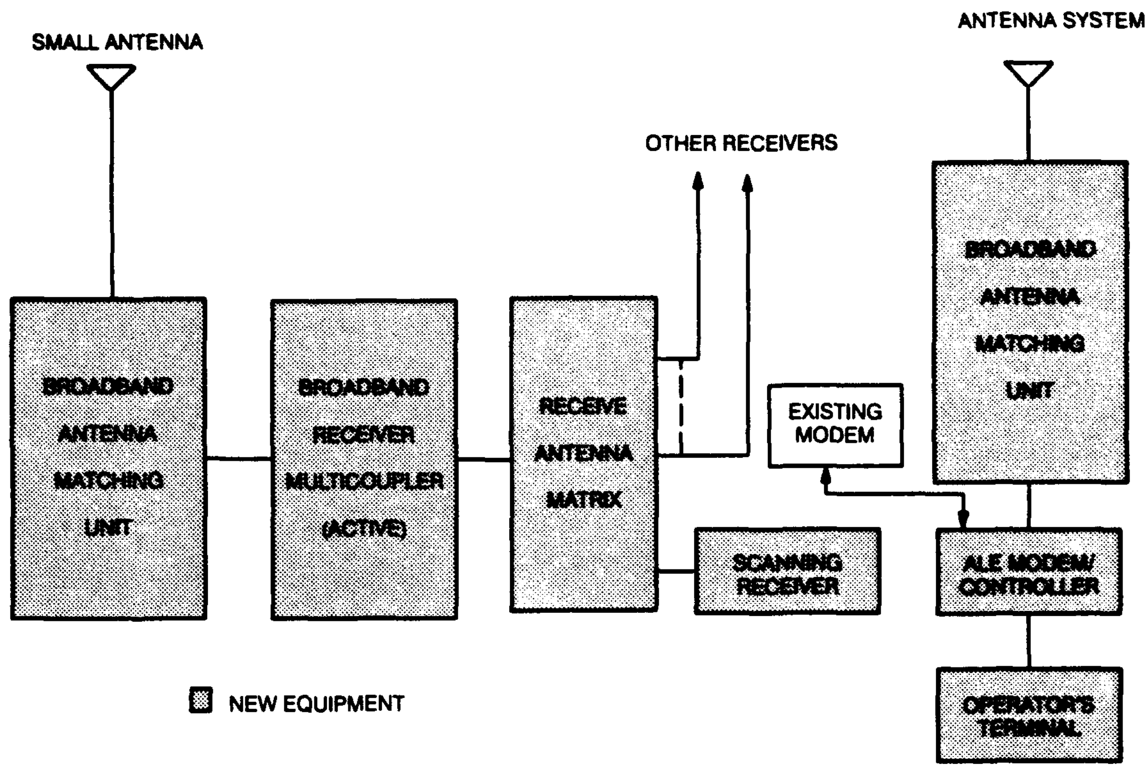

Figure 10. Option 4: Broadband system.

Table 3. Operational rules for ALE (as taken from reference 1).

1. Independent ALE receive capability (in parallel with any others) **CRITICAL**
2. Always listens (for ALE signals) **CRITICAL**
3. Always will respond (unless deliberately inhibited)
4. Always scanning (if not otherwise in use)
5. Will not interfere with active ALE channel (unless have priority or forced)
6. Always will exchange LQA with other stations when requested (unless inhibited), and always measures the signal quality of others
7. Will respond in preset/derived/directed time slot (net/group/special calls)
8. Always seek (unless inhibited) and maintain track of their connectivities with others
9. Linking ALE stations employs highest mutual level of capability
10. Minimizes time on channel
11. Minimizes power used (as capable)

6.0 CONCEPT OF OPERATIONS (CONOPS)

The CONOPS for using ALE from shipboard platforms will depend on how the technique is implemented. Several implementation options have been presented in section 5.0. Not included above, but also important to the CONOPS, is switching available for the ALEM/C and other modems. A CONOPS for each of the options will be discussed below. All of the various options are interoperable with each other and any other system that employs a MIL-STD-188-141A modem/controller.

The CONOPS for ALE from shipboard platforms will be influenced by the ship's antenna system. Because the antenna radiation patterns are not omnidirectional and are different for each antenna, the same antenna(s) must be used for both the ALE function and the communication service it supports. Also, because of the antennas, the LQA tables may be valid for only short periods of time as the ship steams and changes course.

6.1 OPERATION RULES FOR ALE

MIL-STD-188-141A states that the ALE system shall incorporate the operational rules listed in table 3. Rule 2 is not required during temporary periods when not technically feasible (e.g., during transmit with a transceiver or when using a common antenna with a transmitter and receiver).

6.2 CONOPS PER OPTION

As stated previously, all of these options are interoperable with each other and any other system using a MIL-STD-188-141A modem. However, the capability will be determined by the implementation used. All of the options, except option 2, can abide by the rules stated in table 4.

6.2.1 Option 1: Automatic ALE Transceiver

This option, as shown in figure 4, provides fully capable ALE support to a single communication service. The service is dependent on the modem used. With the addition of a switch between the external modem and the ALEM/C, several services could be supported one at a time. Any of the features of MIL-STD-188-141A can be used with this option.

This option will not support any communication services requiring duplex circuits. Because of antenna pattern differences, this option can not provide reliable frequency selection guidance to other subsystems.

The CONOPS for this option would be to select the features of the MIL-STD required to operate the circuit needed to provide the communication service. Available frequencies would depend on the strategy used for frequency management. This will be discussed later in this report.

6.2.2 Option 2: ALE Modem/Controller

This option, as shown in figure 5, provides a very limited capability to support several communication services (one at a time). The service is dependent on the rest of the system. With the

addition of switch matrices between ALEM/C and receiver and existing modems, several services could be supported one at a time.

This option can not invoke operational rule 4 because it is limited to a fixed frequency. It will provide a very limited capability with regard to rules 6 through 9.

The CONOPS for this option would be selection of the service to be supported, placement of the ALEM/C into the system, and setup to operate on the assigned frequency. Once the circuit is established, the ALEM/C could be switched into another system. The ALEM/C would be used with systems in order of priority starting with the highest.

6.2.3 Option 3: Broadband Receiving Subsystem

This option (figures 6 through 9) provides a limited capability to support link establishment for one service while providing LQA information for up to 19 other communication services. Except for option 3D, the number and distribution of frequencies is limited by the manually tuned AN/SRA-49. The response time to answer a call is determined by the time to manually tune the transmit subsystem.

The CONOPS for this option would be either of two ways: (1) Support one communication service by establishing the link and then use an existing modem while providing LQA information for other services; or (2) determine LQAs for the various frequencies/circuits and provide that information to the subsystems that support the various services. The transmit subsystem would have to be manually tuned to initiate or answer a call. Frequencies would be managed in such a way that the frequencies with the best LQAs would be assigned to the highest priority services. More will be discussed below on this frequency management concept.

6.2.4 Option 4: Broadband System

This option (figure 10) provides a fully compatible ALE capability only limited by the particular ALEM/C chosen for implementation. All of the functions required by MIL-STD-188-141A can be used with this option.

The CONOPS for this option would have the ALEM/C measure the LQAs for all the frequencies assigned to the ship/battlegroup and provide that information to a frequency manager who would assign the frequencies to various services. Through interaction with the power control of the transmit subsystem, the minimum power for acceptable communication could be determined.

6.3 FREQUENCY MANAGEMENT WITH ALE

The implementation of ALE in accordance with appendix A of MIL-STD-188-141A will allow a break from the traditional way of frequency assignment/management. Traditionally, two frequencies are assigned to each communication service; one is the primary and the second is a backup. The performance of a frequency used for a link to provide a service is a function of time of year, time of day, geographic location, sunspot activity, length of link, transmit power, and antenna performance. Often, very little attention is paid to these factors when assigning frequencies to a link.

By using the features of the ALE standard, frequency management can be approached differently and can break from tradition. By using the sounding and LQA capability, the influence of all the factors listed above are included for each frequency over each link. Frequency management with increased performance could be accomplished with the following steps:

a. Treat all the frequencies assigned to the platform/battlegroup as a pool.

b. Rank in order of performance all frequencies between all platforms by using LQA.

c. Rank in order of priority all communication services between platforms.

d. Assign communication services in order of priority to frequencies ordered by LQA.

e. Use the voice or data message capability of the ALEM/C to coordinate frequency assignments.

When a large number of frequencies/platforms are involved, it would be much more efficient to establish subsets of frequencies per platform using a prediction program such as PROPHET, IONCAP, etc. The most probable propagating frequencies would make up the subsets.

7.0 SYSTEM ENGINEERING ANALYSIS

A system engineering analysis of the various options will serve as a method to select the recommended approach to implement the ALE capability into existing ship HF communication systems. Option 4 provides the greatest capability for the use of ALE. However, it requires a completely new HF communication system on almost all existing ships on which it would not be cost effective just to add an ALE capability. Options 1 and 2 provide a capability that is too limited to be of much use. This leaves option 3 to be analyzed. Options 3A, 3B, and 3C appear to have the potential to provide good ALE capability at a reasonable cost. Option 3D was not included because it requires a new and potentially expensive broadband receiving subsystem.

7.1 METHODOLOGY

Considering the above, the analysis was performed on options 3A, 3B, and 3C. The analysis consists of calculating the system noise figure, sensitivity, dynamic range, and cost. Each of the options were evaluated for three configurations: (1) without RF amplifier; (2) with 10-dB gain amplifier; and (3) with 20-dB gain amplifier. The data from this analysis are contained in figures 11 through 43 and tables 4 through 18. A representative set of costs for various components is contained in table 19.

7.2 RESULTS

The data were analyzed for each of the parameters listed above in the various configurations. The best system noise figure was provided by option 3C-1 for either the 10-dB or 20-dB amplifier configuration. The system noise figure without an amplifier is considered too high. The maximum variation across the options with the 20-dB amplifier was 4.4 dB and with the 10-dB amplifier was 2.5 dB. The noise figures provided with the 10-dB amplifier are sufficient for

good receive system performance. All system noise figures with amplifiers are less than those provided by the basic system (multicoupler + receiver.)

The best sensitivity using a 10-dB amplifier is provided by option 3C-1. The variation over all the various options is only 2.5 dB. The sensitivity for each option that uses an amplifier exceeds that of the basic system.

The dynamic range for the options using the 10-dB amplifier is either 95 or 96 dB at 2 MHz. This is better dynamic range than that provided by the options using the 20-dB amplifier. However, it is 4 or 5 dB less dynamic range than that provided by the basic system. The reduction in dynamic range seems reasonable considering the increased overall performance that is gained by using ALE.

The amplifier option with the lowest estimated cost is option 3C-2 ($2830) followed by option 3B-2 ($7110.) The estimated costs for the various options range from $2830 to $37,240.

A comparison of the performance of options 3B-2 and 3C-2 shows that option 3C-2 is about 0.5 dB better in noise figure and sensitivity and has a $4280 lower estimated cost. However, option 3B-2 is the recommended approach because it would allow the addition of another ALE capability without any changes and provide access by other receivers to any of the 20 frequencies tuned up on the AN\SRA-49 without patching or switching.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been reached by this study:

1. Options to implement an ALE capability are on every navy ship. The capability will be a function of the option used.
2. All of the options presented are interoperable with each other and with any other system employing an ALEM/C that meets MIL-STD-188-141A.
3. CONOPS will be a function of the implementation option.
4. ALE supports a new frequency management philosophy that will improve the HF system performance.

The recommendations are:

1. Install ALEM/Cs on every navy ship in a quantity equal to the number of different receiving subsystems plus one.
2. Use Option 3D where possible with Option 3B-2 as an alternative for ships with an AN/SRA-49.
3. Manage the set of HF frequencies with the new strategy presented in paragraph 6.3.

9.0 REFERENCES

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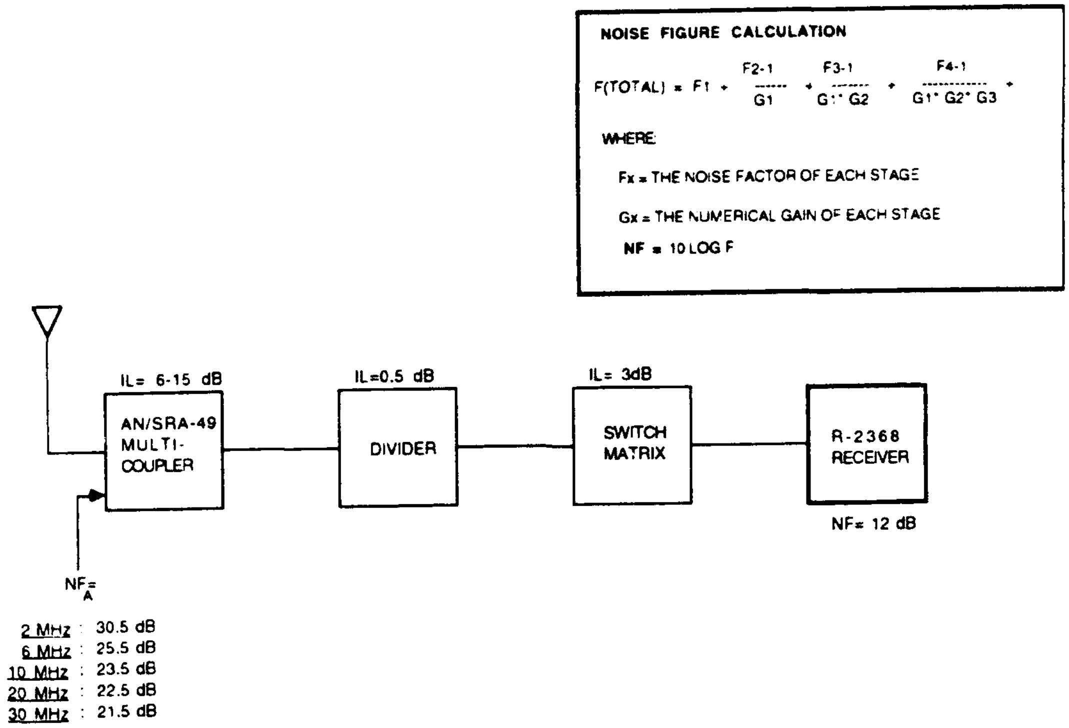

Figure 11. Noise figure calculations for option 3A: Broadband receiving system.

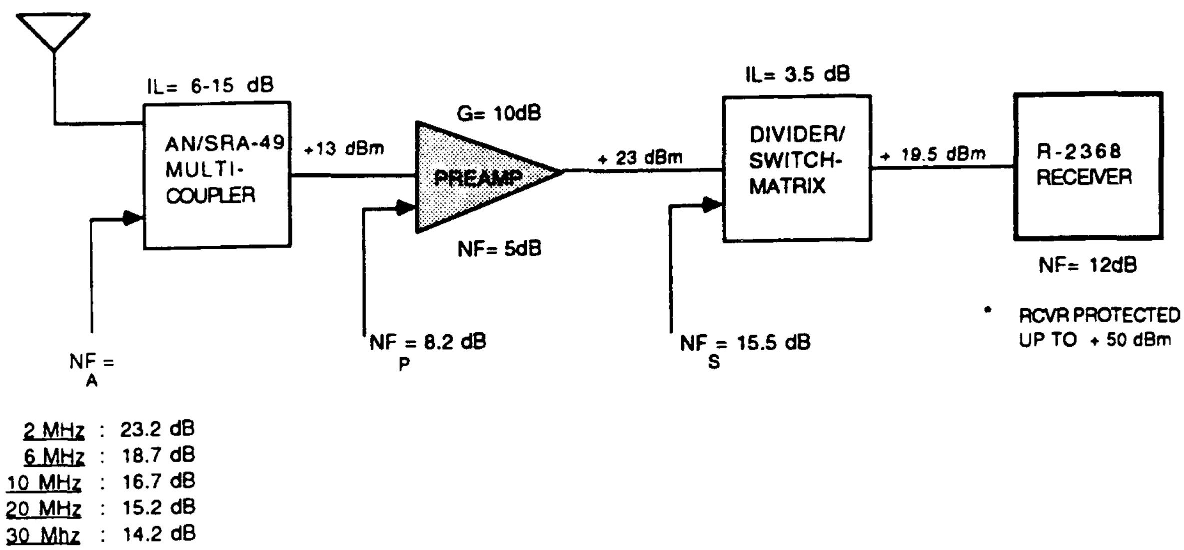

Figure 12. Noise figure calculations for option 3A-1: Broadband receiving system with preamp (G = 10 dB).

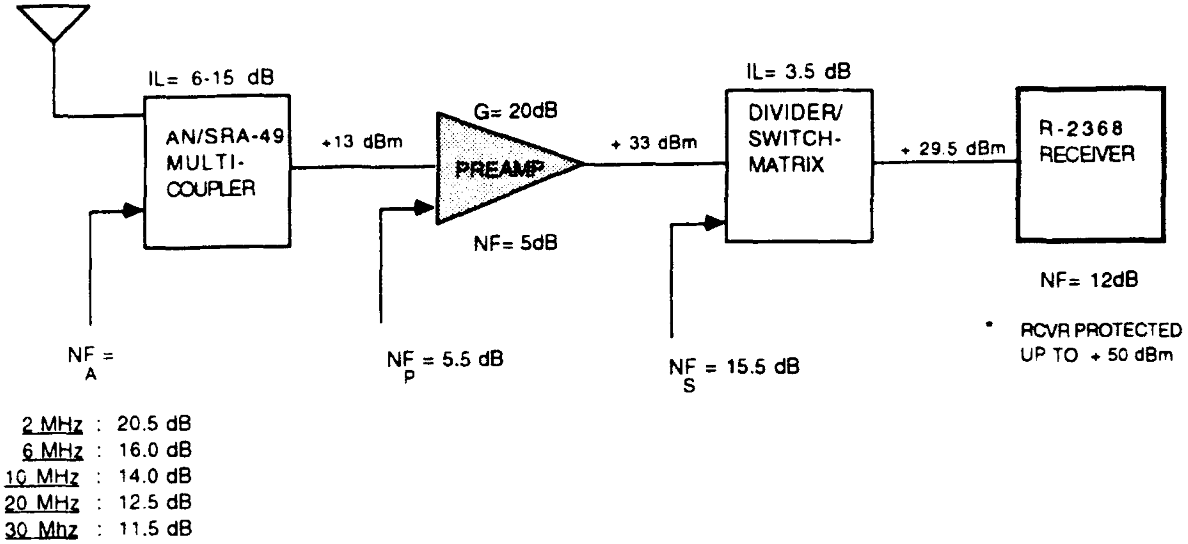

Figure 13. Noise figure calculations for option 3A-1: Broadband receiving system with preamp (G = 20 dB).

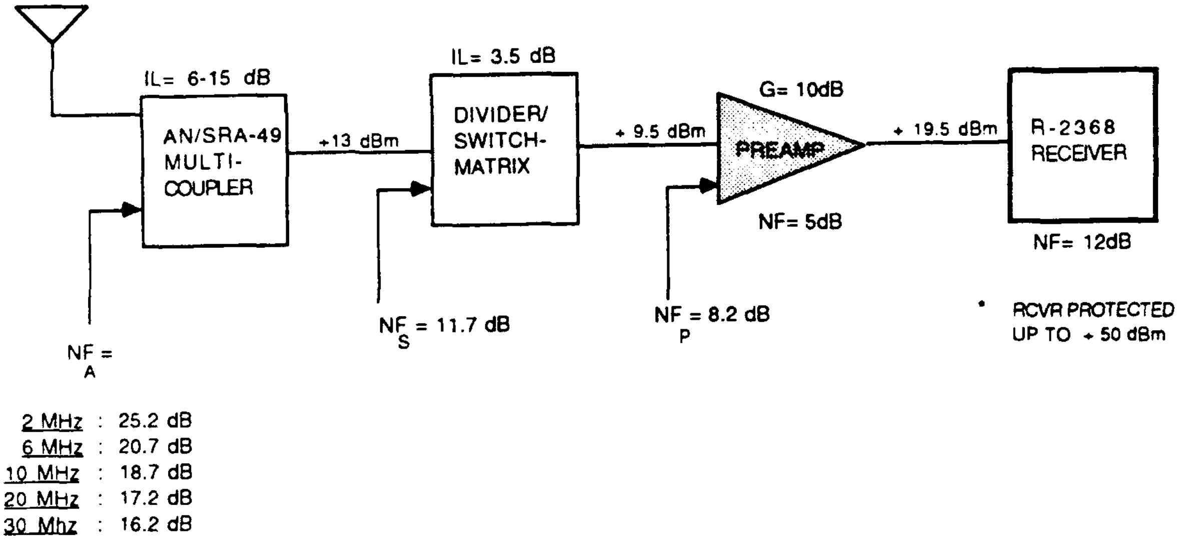

Figure 14. Noise figure calculations for option 3A-2: Broadband receiving system with preamp (G = 10 dB).

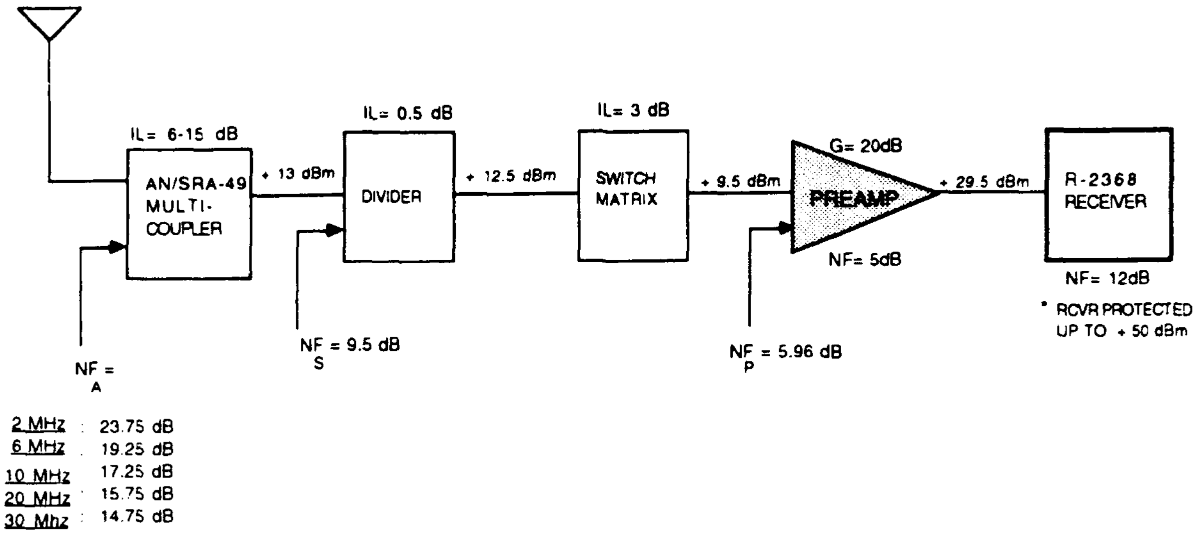

Figure 15. Noise figure calculations for option 3A-2: Broadband receiving system with preamp (G = 20 dB).

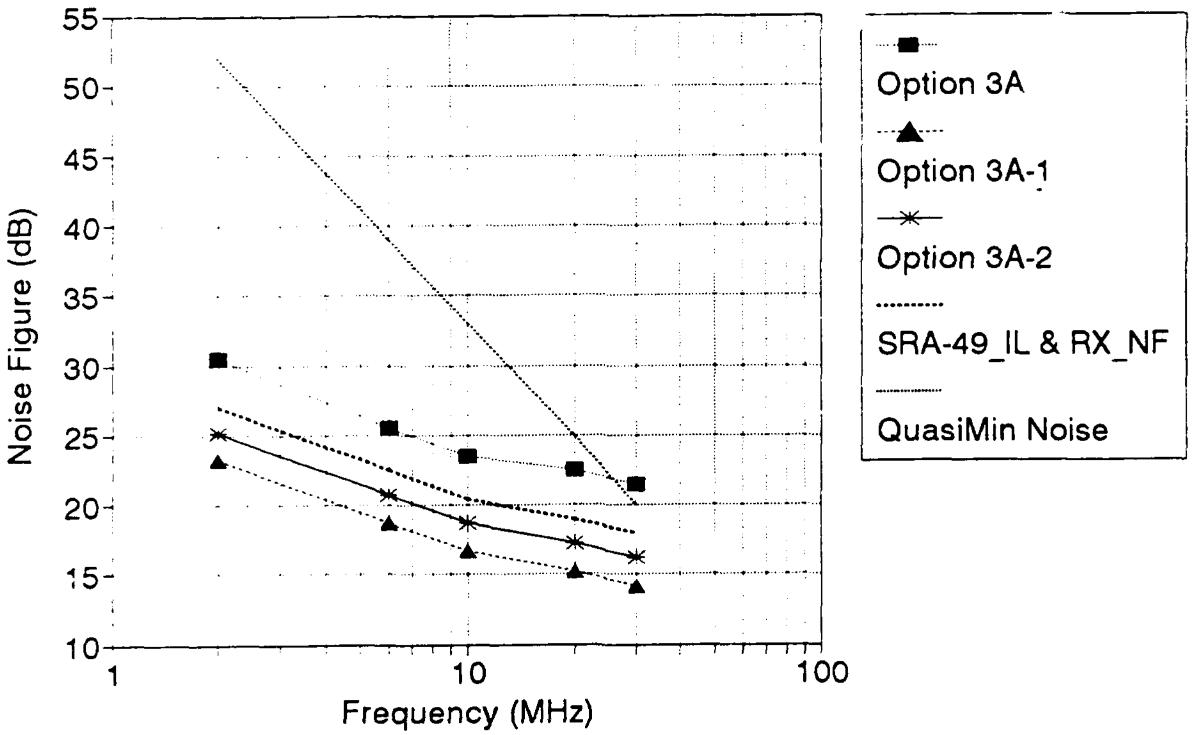

Figure 16. Option 3A noise figures with preamp gain = 10 dB.

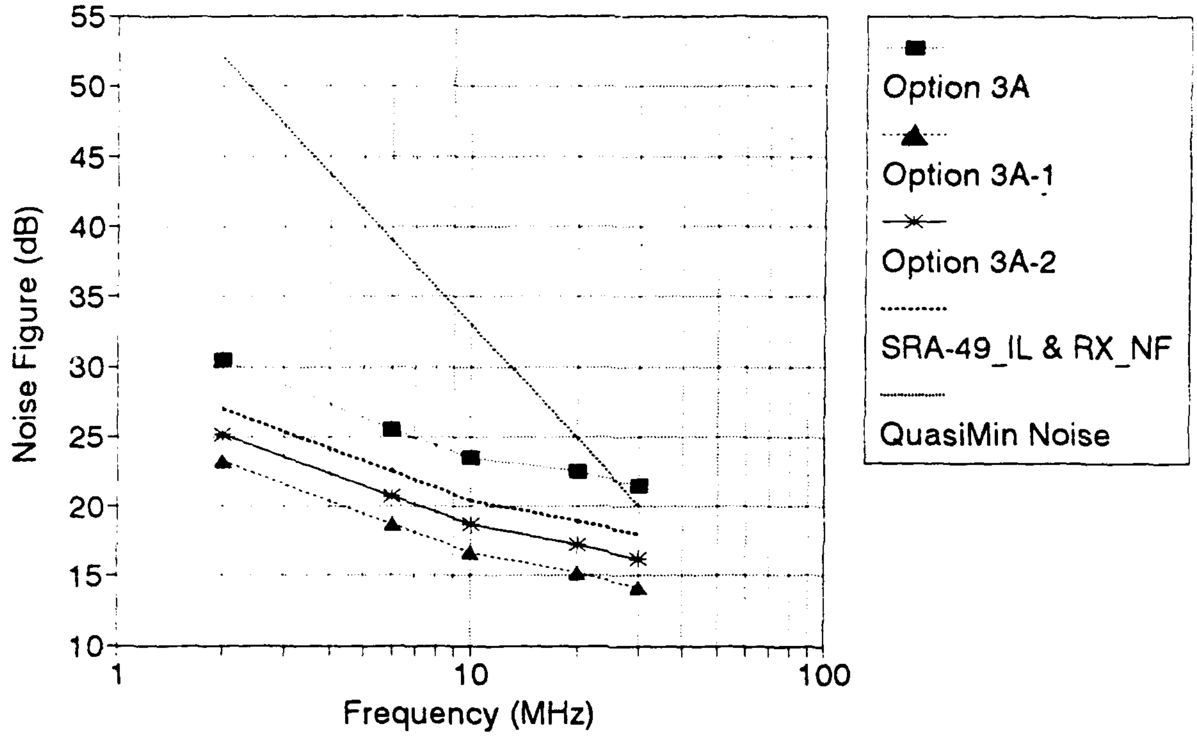

Figure 17. Option 3A noise figures with preamp gain = 20 dB.

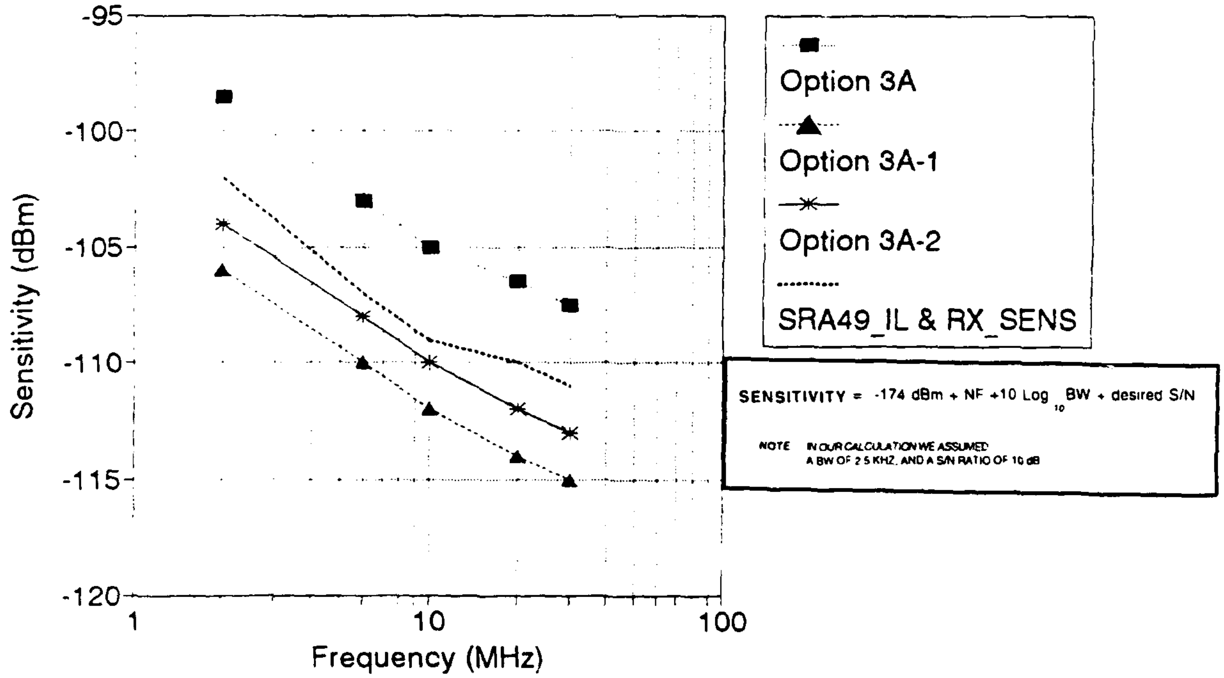

Figure 18. Option 3A sensitivity plot with preamp gain = 10 dB.

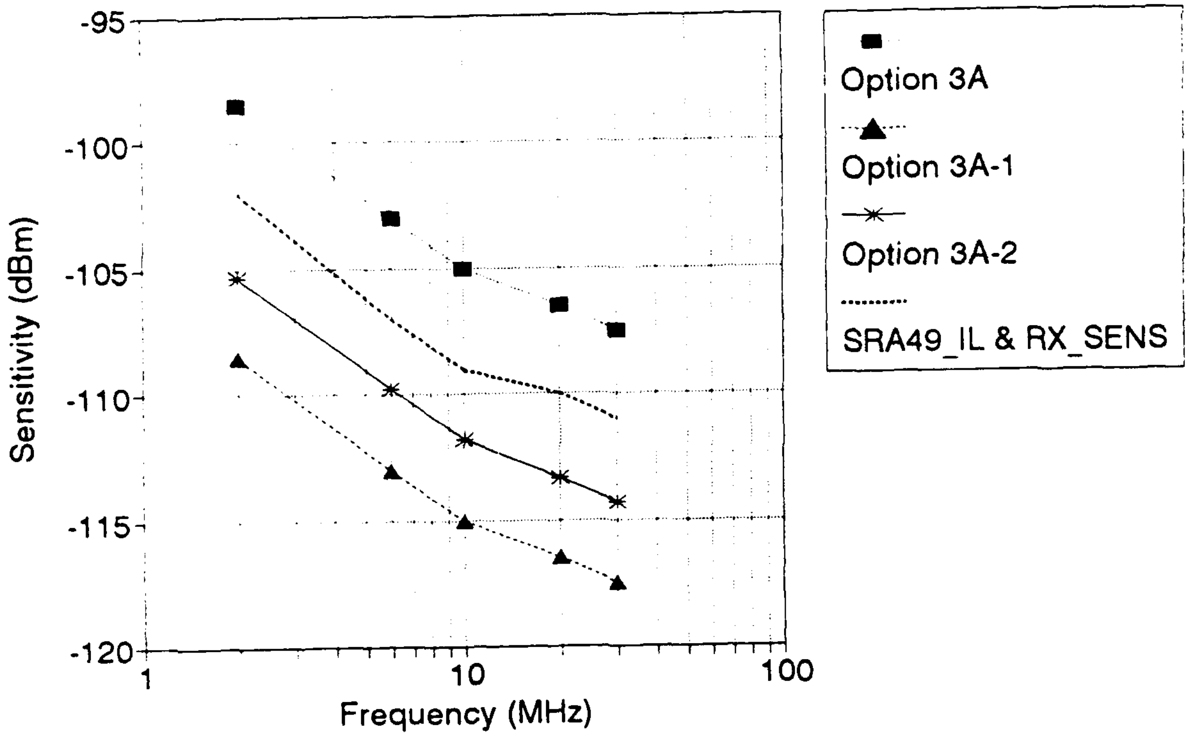

Figure 19. Option 3A sensitivity plot with preamp gain = 20 dB.

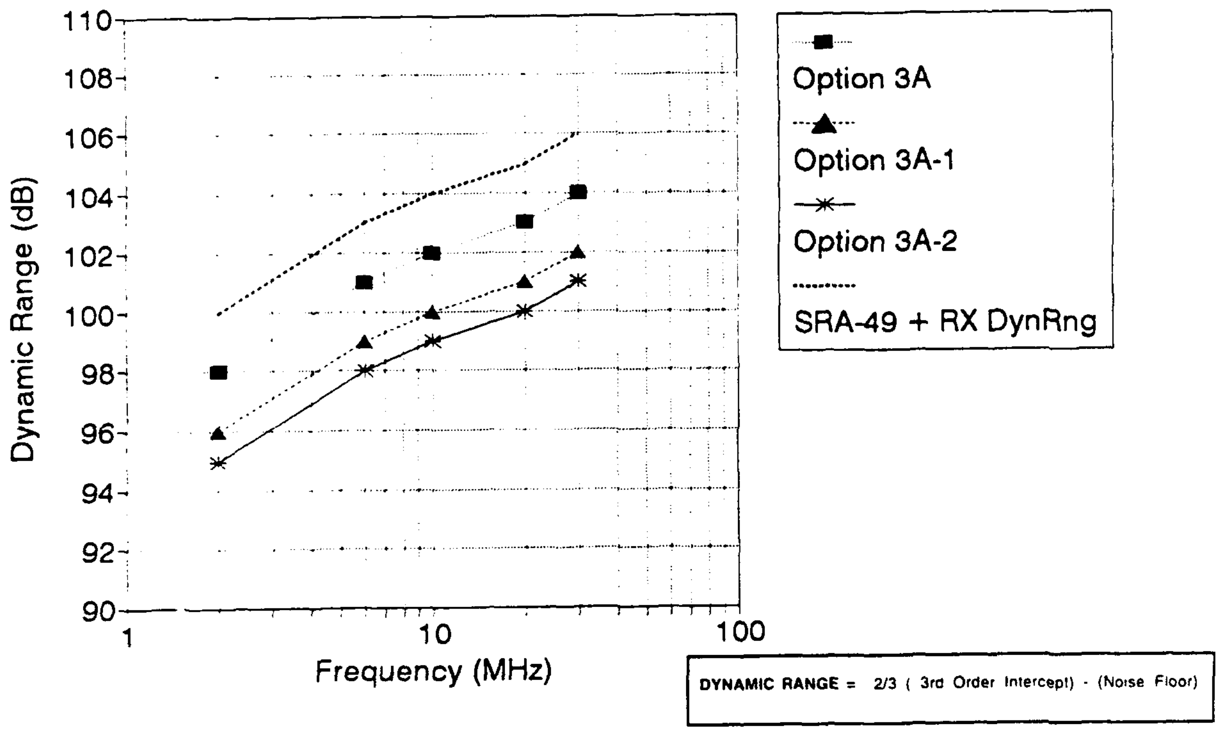

Figure 20. Option 3A sensitivity plot with preamp gain = 10 dB.

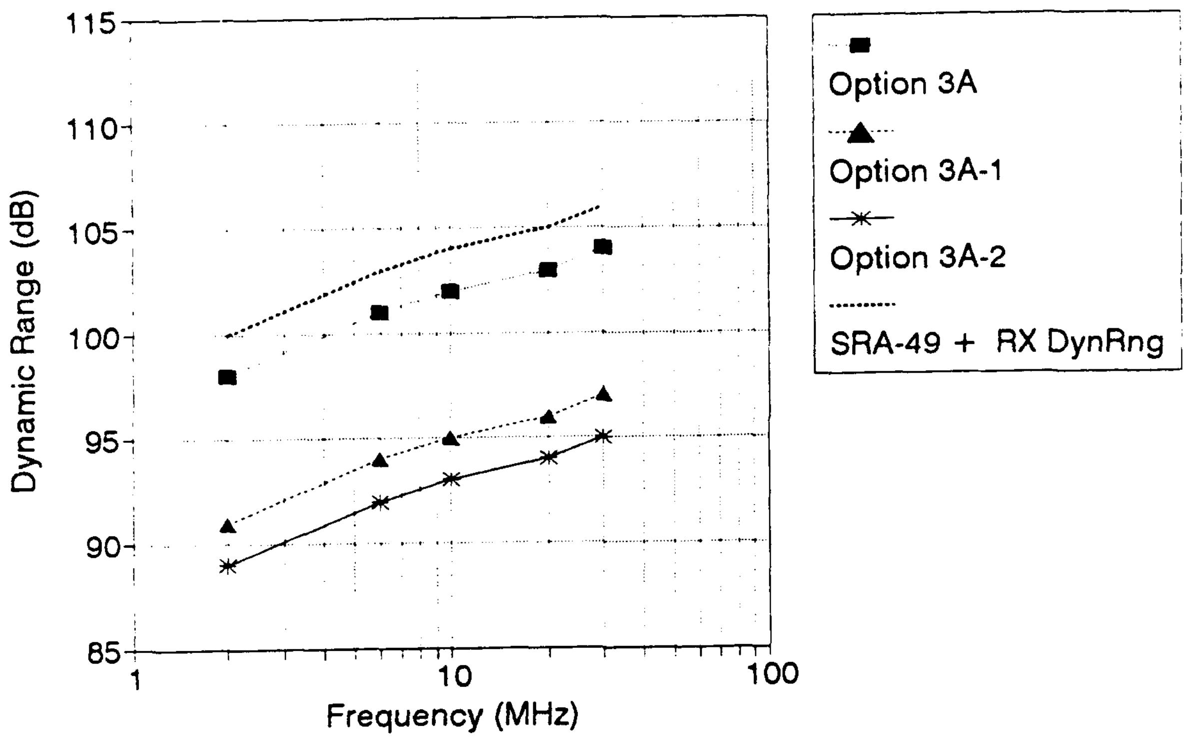

Figure 21. Option 3A dynamic range plot with preamp gain = 20 dB.

Table 4. Noise figure calculations for option 3A (preamp G = 20 dB).

FREQ (MHz)	OPTION 3A NF (dB)	OPTION 3A-1 NF (dB)	OPTION 3A-2 NF (dB)	SRA-49 IL (dB)	QminNOISE (dB)
2.0	30.5	20.5	23.8	15.0	52.0
6.0	25.5	16.0	19.3	10.5	39.0
10.0	23.5	14.0	17.3	8.5	33.0
20.0	22.5	12.5	15.8	7.0	24.9
30.0	21.5	11.5	14.8	6.0	20.0

Table 5. Noise figure calculations for option 3A (preamp G = 10 dB).

FREQ (MHz)	OPTION 3A NF (dB)	OPTION 3A-1 NF (dB)	OPTION 3A-2 NF (dB)	SRA-49 IL (dB)	QminNOISE (dB)
2.0	30.5	23.2	25.2	15.0	52.0
6.0	25.5	18.7	20.7	10.5	39.0
10.0	23.5	16.7	18.7	8.5	33.0
20.0	22.5	15.2	17.2	7.0	24.0
30.0	21.5	14.2	16.2	6.0	20.0

Table 6. Option 3A-1 system tradeoff considerations.

AT FREQ = 2 MHz	OPTION 3A	**OPTION 3A-1** W/ 20 dB GAIN PREAMPLIFIER	**OPTION 3A-1** W/ 10 dB GAIN PREAMPLIFIER
Noise Figure (dB)	30.5	20.5	23.2
Sensitivity (dBm)	−98.5	−111.5	−105.8
3Rd Order I.P. (dBm)	+48.0	+28	+38
Dynamic Range (dB)	98	93	96

Table 7. Option 3A-2 system tradeoff considerations.

AT FREQ = 2 MHz	OPTION 3A	**OPTION 3A-1** W/ 20 dB GAIN PREAMPLIFIER	**OPTION 3A-1** W/ 10 dB GAIN PREAMPLIFIER
Noise Figure (dB)	30.5	23.8	25.2
Sensitivity (dBm)	−98.5	−105.3	−103.8
3Rd Order I.P. (dBm)	+48.0	+28	+38
Dynamic Range (dB)	98	89	95

Table 8. Option 3A cost comparisons.

OPTION 3A	DIVIDERS	$1,440
– 20 POWER DIVIDERS	SWITCH MATRIX	$19,800
– 2 SWITCH MATRIX	TOTAL	**$21,240**

OPTION 3A-1	PREAMPLIFIERS	$16,000
– 20 PREAMPLIFIERS	DIVIDERS	$1,440
– 20 POWER DIVIDERS	SWITCH MATRIX	$19,800
– 2 SWITCH MATRIX	TOTAL	**$37,240**

OPTION 3A-2	PREAMPLIFIER	$800
– PREAMPLIFIER	DIVIDERS	$1,440
– 20 POWER DIVIDERS	SWITCH MATRIX	$19,800
– 2 SWITCH MATRIX	TOTAL	**$22,040**

(See table 20)

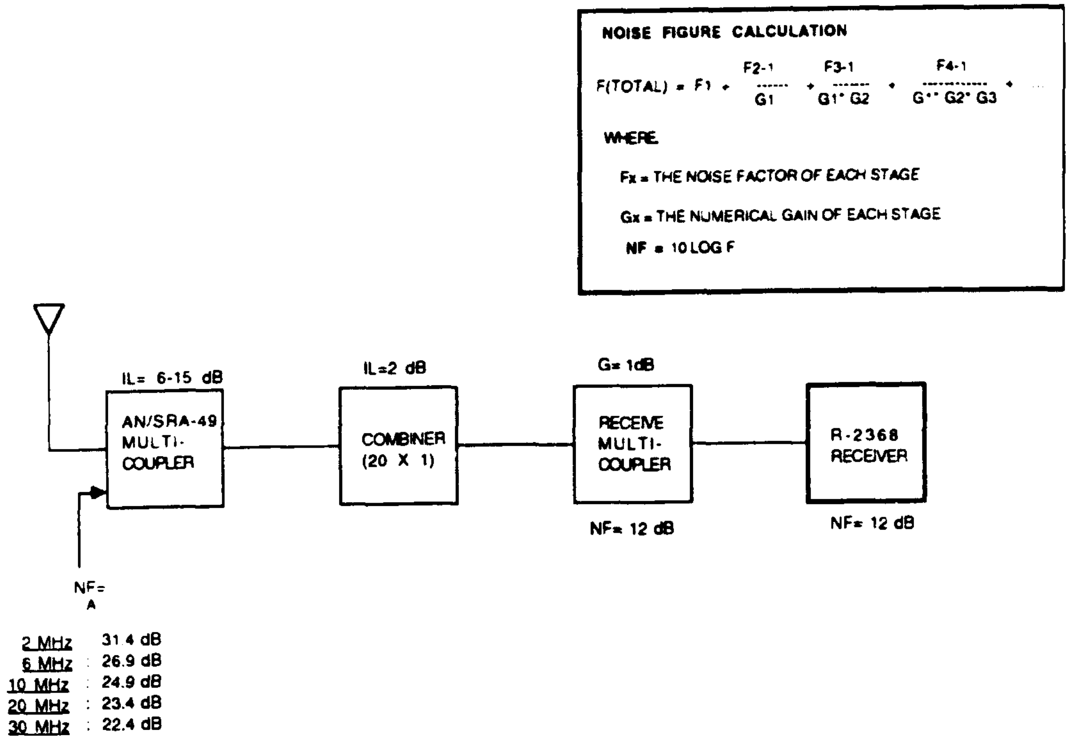

Figure 22. Noise figure calculations for option 3B: Broadband receiving system.

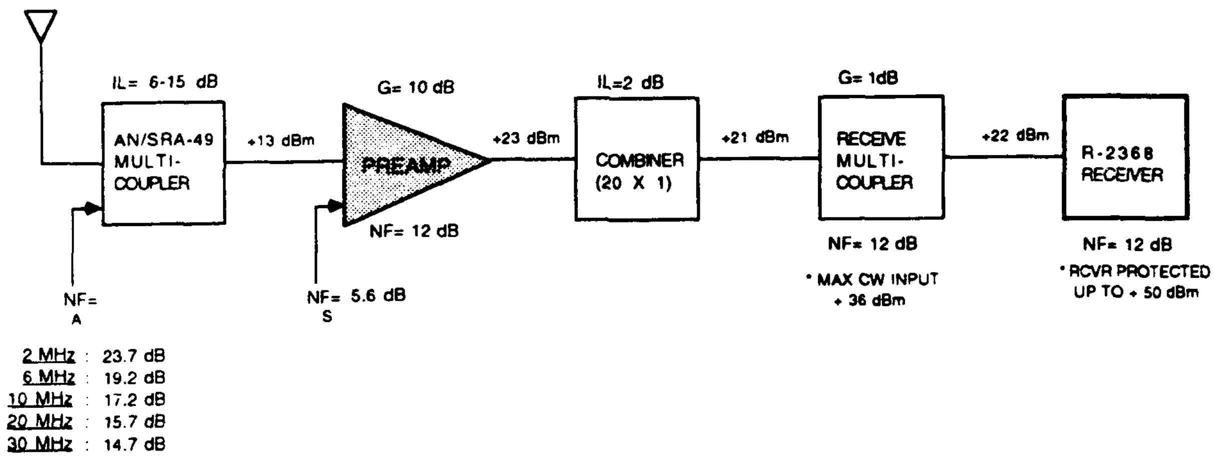

Figure 23. Noise figure calculations for option 3B-1: Broadband receiving system with preamp (G = 10 dB).

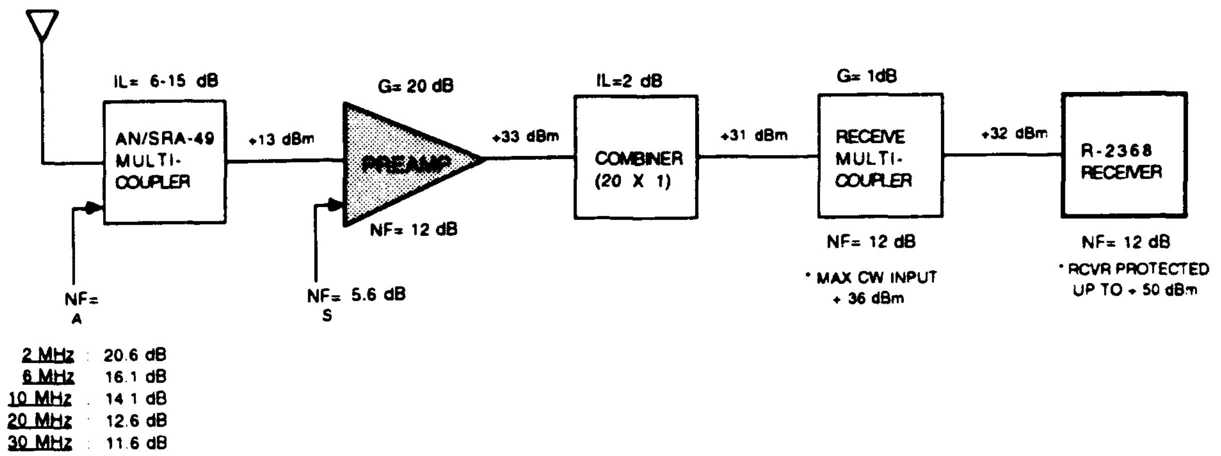

Figure 24. Noise figure calculations for option 3B-1: Broadband receiving system with preamp (G = 20 dB).

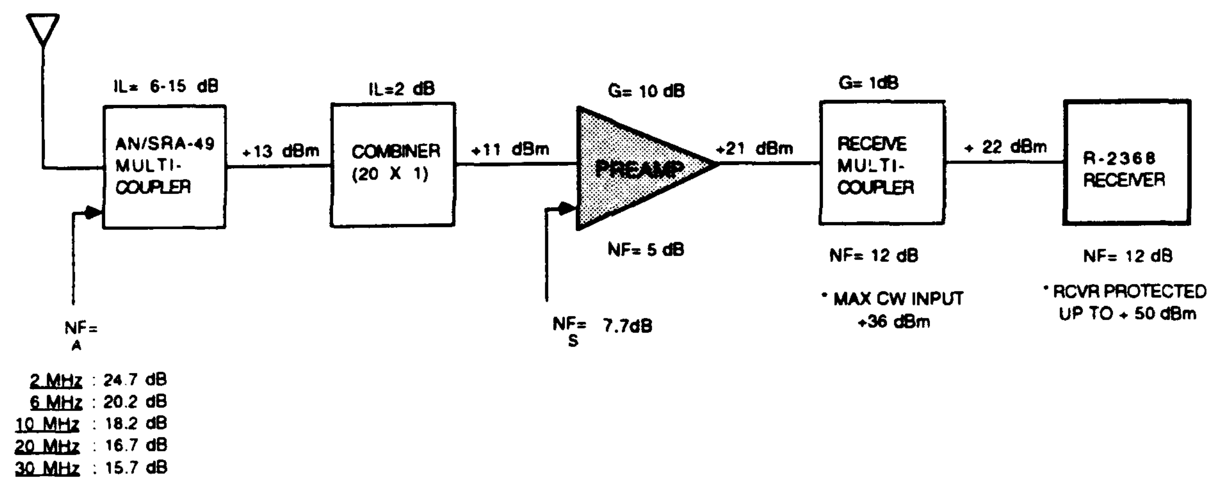

Figure 25. Noise figure calculations for option 3B-2: Broadband receiving system with preamp (G = 10 dB).

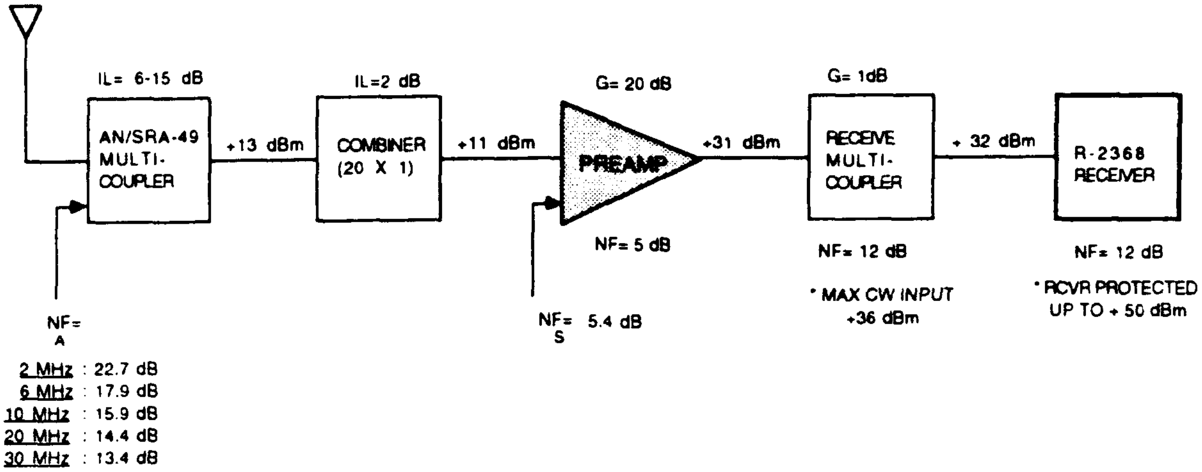

Figure 26. Noise figure calculations for option 3B-2: Broadband receiving system with preamp (G = 20 dB).

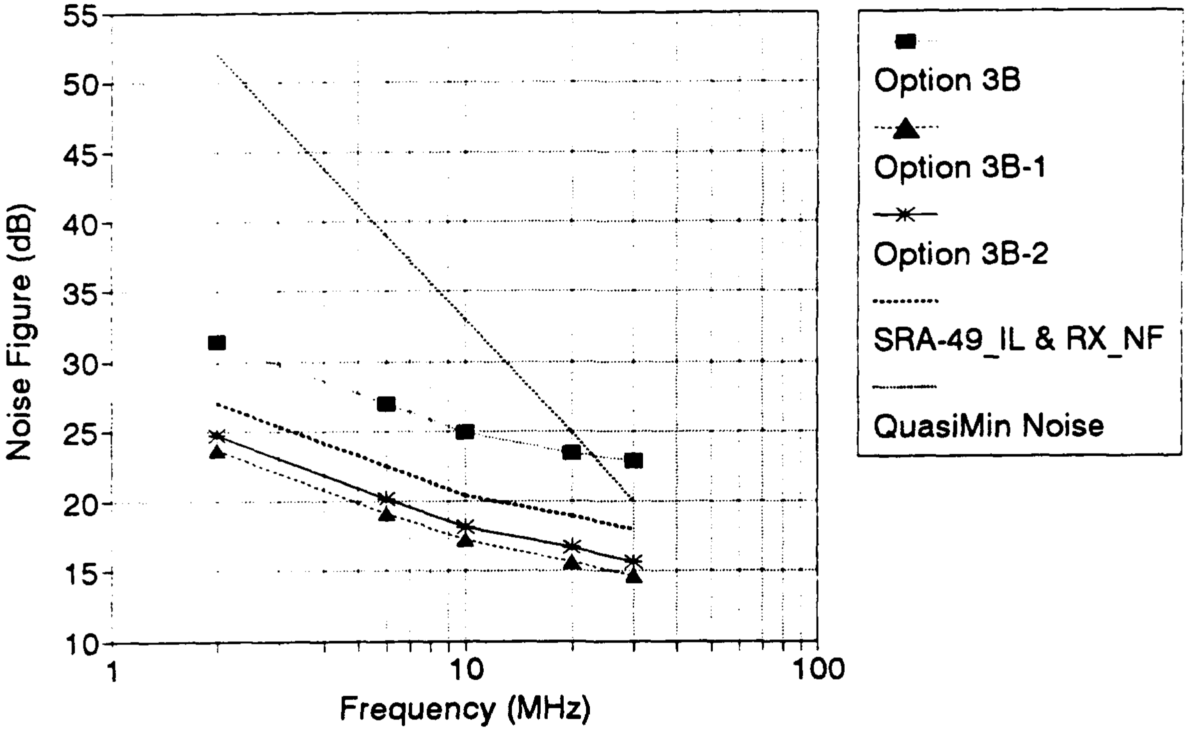

Figure 27. Option 3B noise figures with preamp gain = 10 dB.

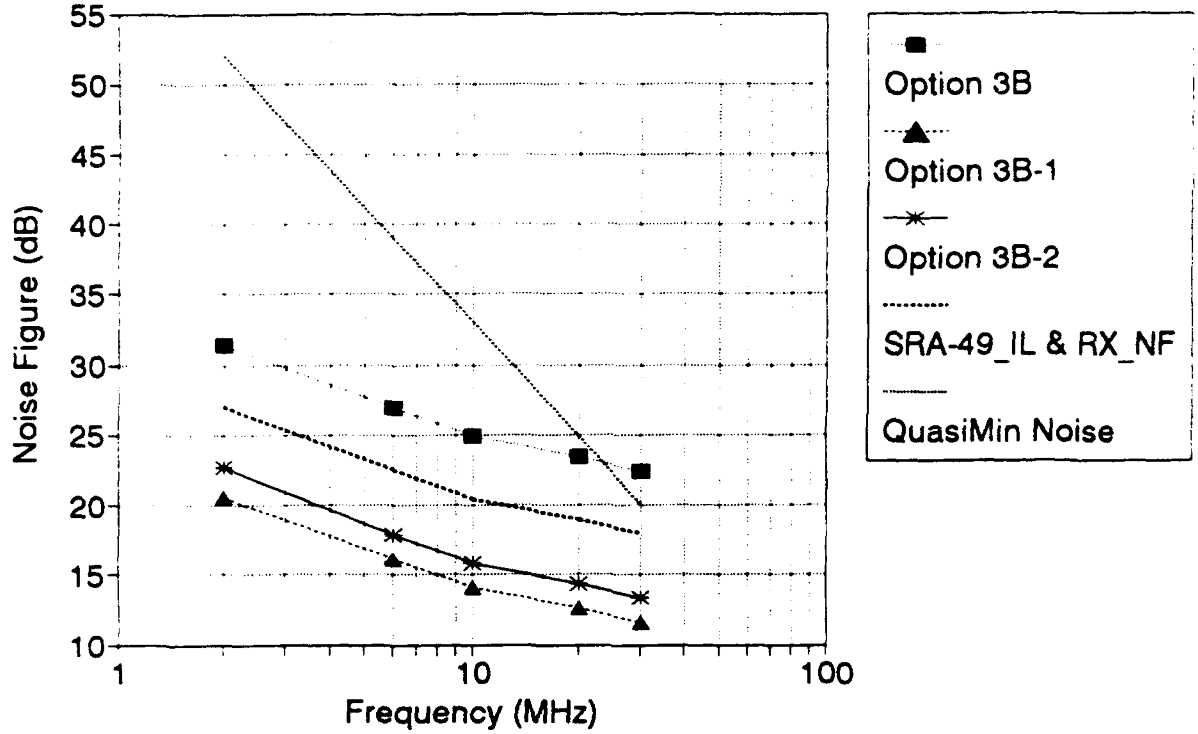

Figure 28. Option 3B noise figures with preamp gain = 20 dB.

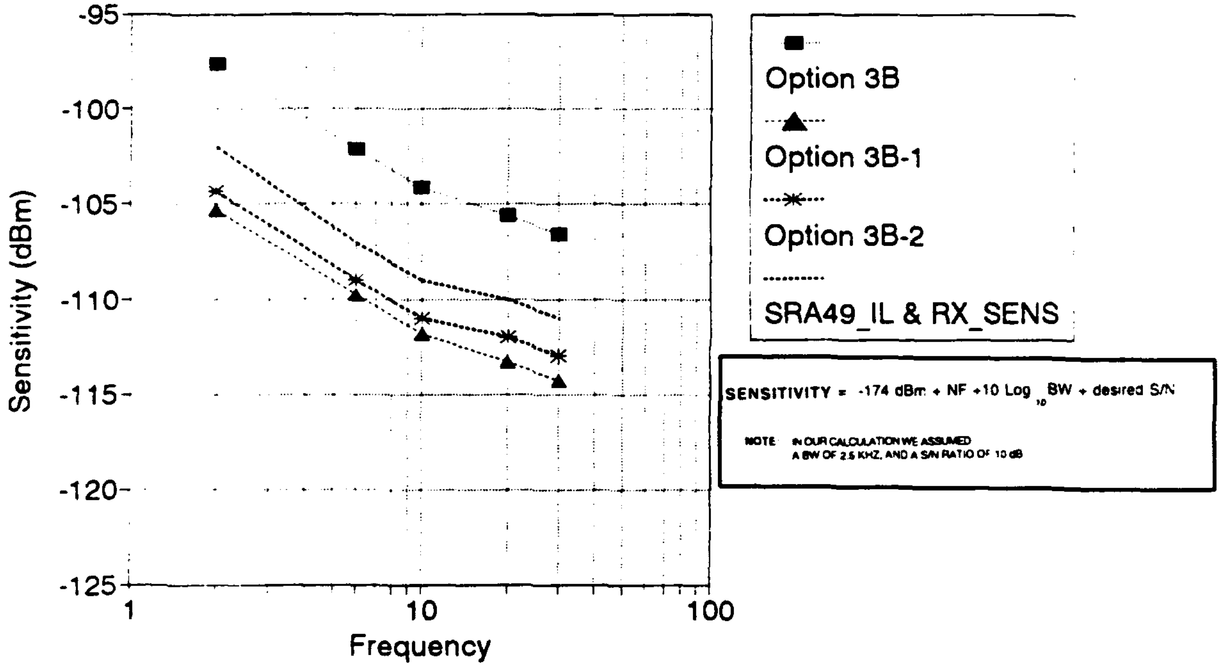

Figure 29. Option 3B sensitivity plot with preamp gain = 10 dB.

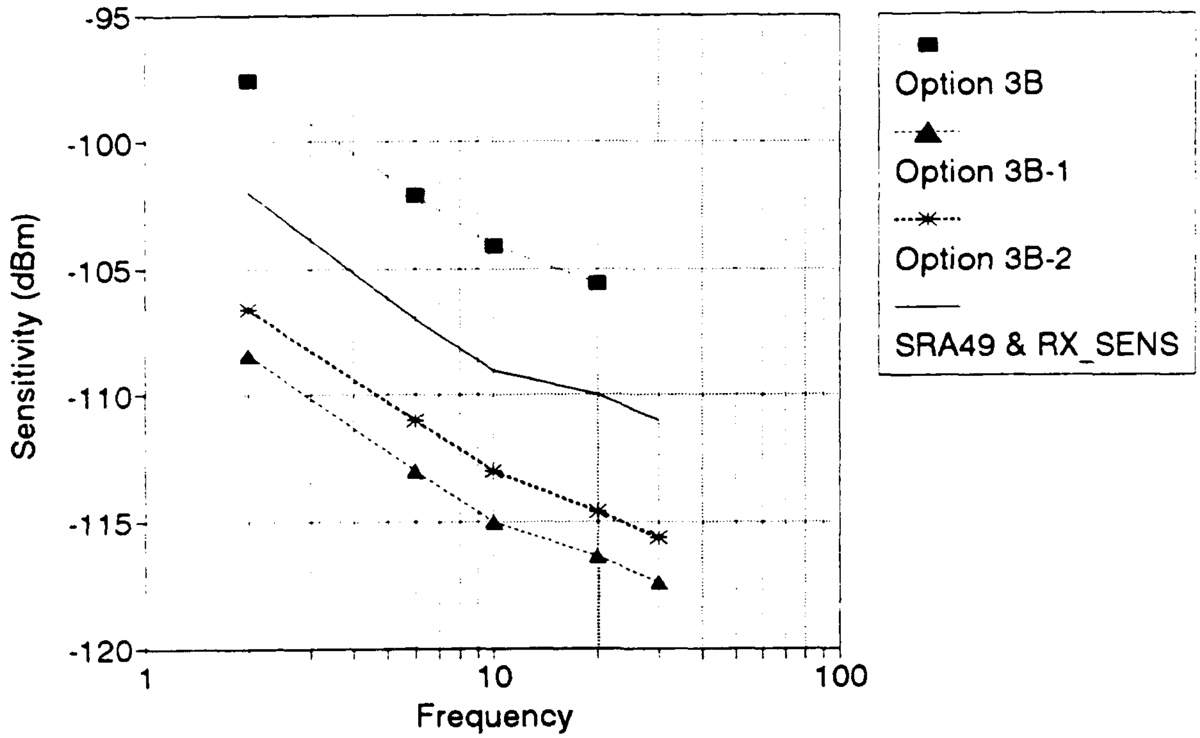

Figure 30. Option 3B sensitivity plot with preamp gain = 20 dB.

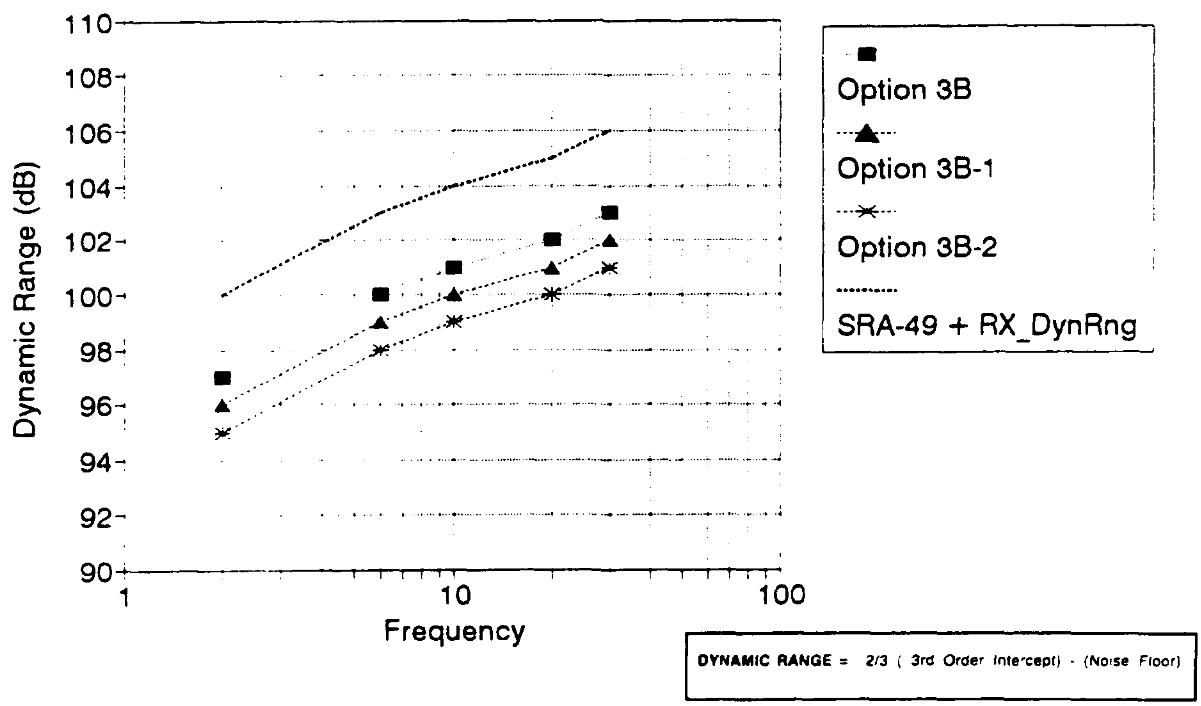

Figure 31. Option 3B dynamic range plot with preamp gain = 10 dB.

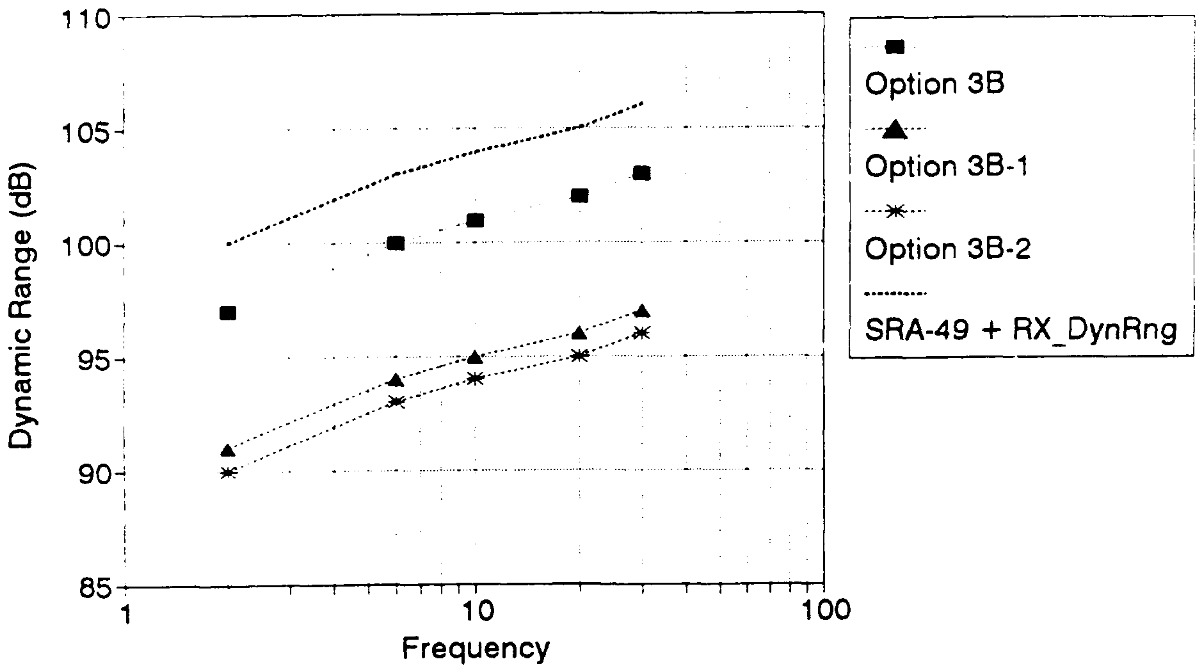

Figure 32. Option 3B dynamic range plot with preamp gain = 20 dB.

Table 9. Noise figure calculations for option 3B (preamp G = 20 dB).

FREQ (MHz)	OPTION 3B **NF** (dB)	OPTION 3B-1 **NF** (dB)	OPTION 3B-2 **NF** (dB)	SRA-49 **IL** (dB)	QminNOISE (dB)
2.0	31.4	20.6	22.7	15.0	52.0
6.0	26.9	16.1	17.9	10.5	39.0
10.0	24.9	14.1	15.9	8.5	33.0
20.0	23.4	12.6	14.4	7.0	24.0
30.0	22.4	11.6	13.4	6.0	20.0

Table 10. Noise figure calculations for option 3B (preamp G = 10 dB).

FREQ (MHz)	OPTION 3B **NF** (dB)	OPTION 3B-1 **NF** (dB)	OPTION 3B-2 **NF** (dB)	SRA-49 **IL** (dB)	QminNOISE (dB)
2.0	29.5	23.7	24.7	15.0	52.0
6.0	24.5	19.2	20.2	10.5	39.0
10.0	22.5	17.2	18.2	8.5	33.0
20.0	21.5	15.7	16.7	7.0	24.0
30.0	20.5	14.7	15.7	6.0	20.0

Table 11. Option 3B-1 system tradeoff considerations.

AT FREQ = 2 MHz	OPTION 3B	**OPTION 3B-1** W/ 20 dB GAIN PREAMPLIFIER	**OPTION 3B-1** W/ 10 dB GAIN PREAMPLIFIER
Noise (dB)	31.4	20.6	23.7
Sensitivity (dBm)	–97.6	–108.4	–105.3
3Rd Order I.P. (dBm)	+48.0	+28	+38
Dynamic Range (dB)	97	91	96

Table 12. Option 3B-2 system tradeoff considerations.

AT FREQ = 2 MHz	OPTION 3B	**OPTION 3B-1** W/ 20 dB GAIN PREAMPLIFIER	**OPTION 3B-1** W/ 10 dB GAIN PREAMPLIFIER
Noise (dB)	31.4	22.7	24.7
Sensitivity (dBm)	–97.6	–106.6	–104.3
3Rd Order I.P. (dBm)	+48.0	+28	+38
Dynamic Range (dB)	96	90	95

Table 13. Option 3B cost comparisons.

OPTION 3B – 3 POWER COMBINERS – HF MULTICOUPLER		
	HF MULTICOUPLER	$5,720
	COMBINERS	$590
	TOTAL	**$6,310**

OPTION 3B-1 – 20 PREAMPLIFIERS – 3 POWER COMBINERS – HF MULTICOUPLER		
	HF MULTICOUPLER	$5,720
	PREAMPLIFIERS	$16,000
	COMBINERS	$590
	TOTAL	**$22,310**

OPTION 3B-2 – PREAMPLIFIER – 3 POWER COMBINERS – HF MULTICOUPLER		
	HF MULTICOUPLER	$5,720
	PREAMPLIFIER	$800
	COMBINERS	$590
	TOTAL	**$7,110**

(See table 20)

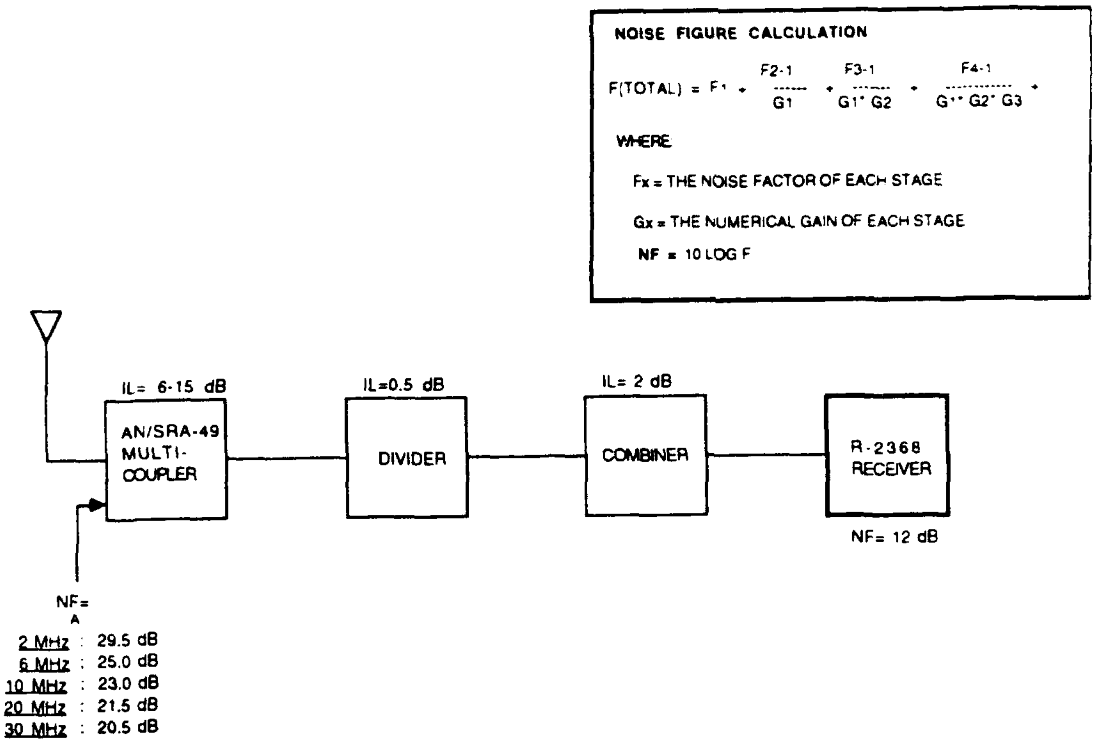

Figure 33. Noise figure calculations for option 3C: Broadband receiving system.

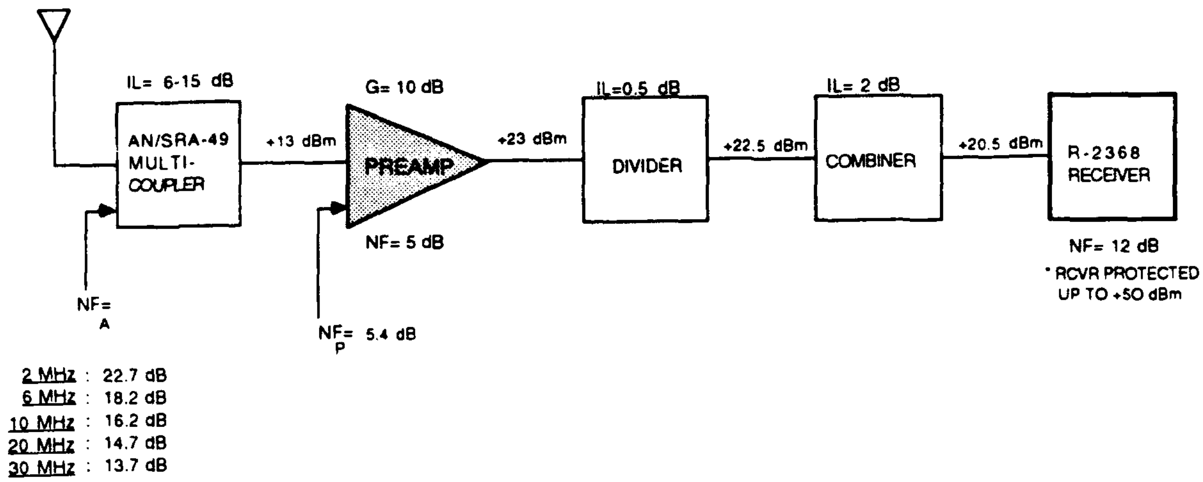

Figure 34. Noise figure calculations for option 3C-1: Broadband receiving system with preamp (G = 10 dB).

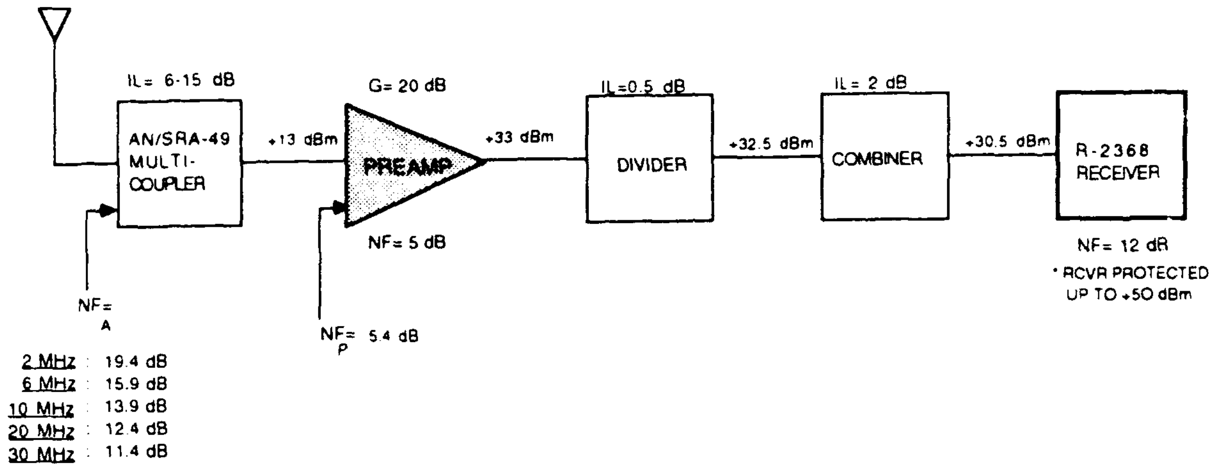

Figure 35. Noise figure calculations for option 3C-1: Broadband receiving system with preamp (G = 20 dB).

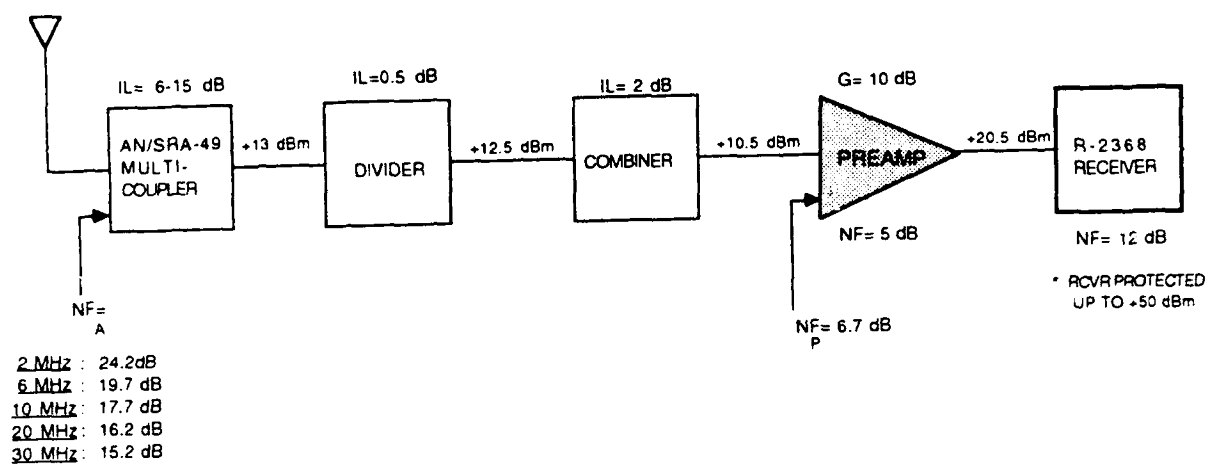

Figure 36. Noise figure calculations for option 3C-2: Broadband receiving system with preamp (G = 10 dB).

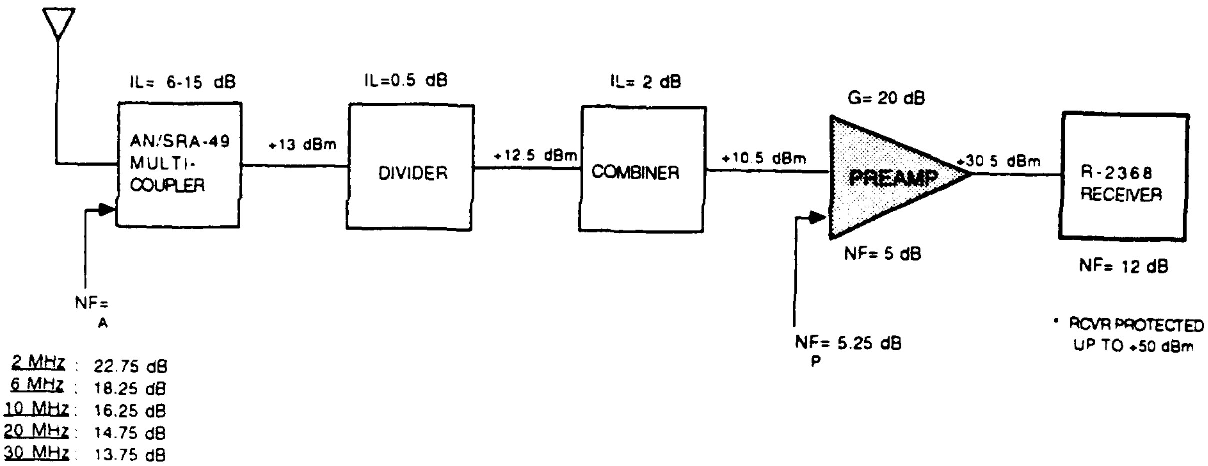

Figure 37. Noise figure calculations for option 3C-2: Broadband receiving system with preamp (G = 20 dB).

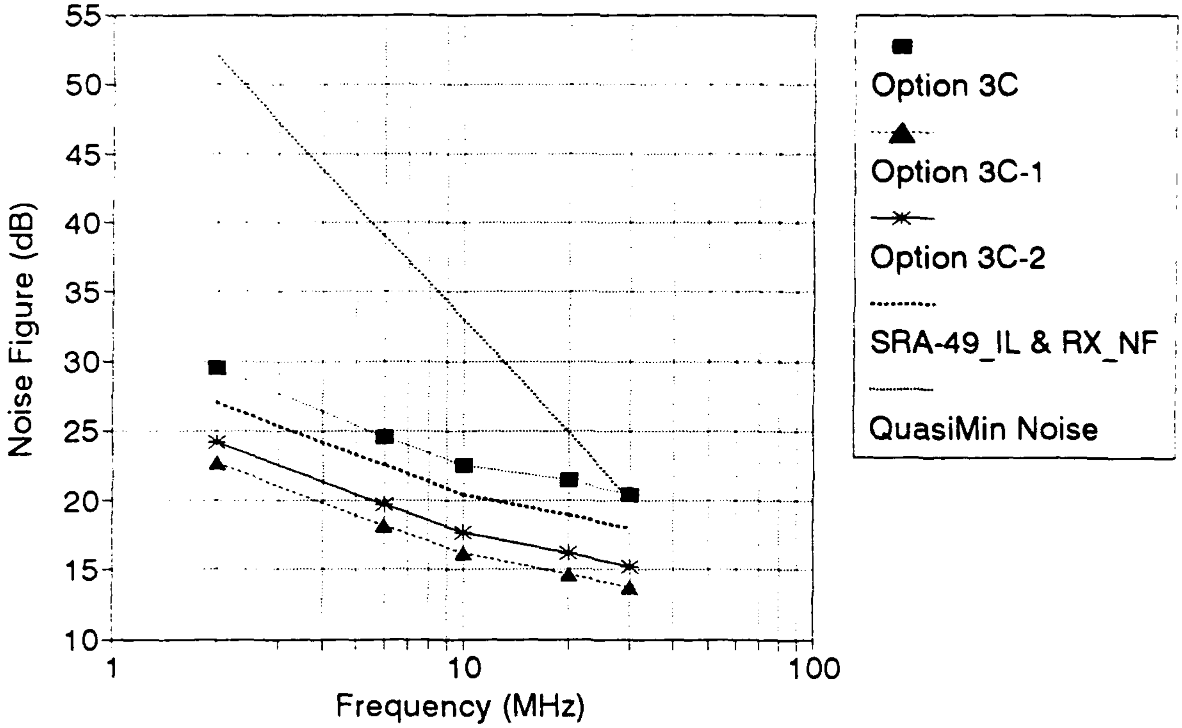

Figure 38. Option 3C noise figures with preamp gain = 10 dB.

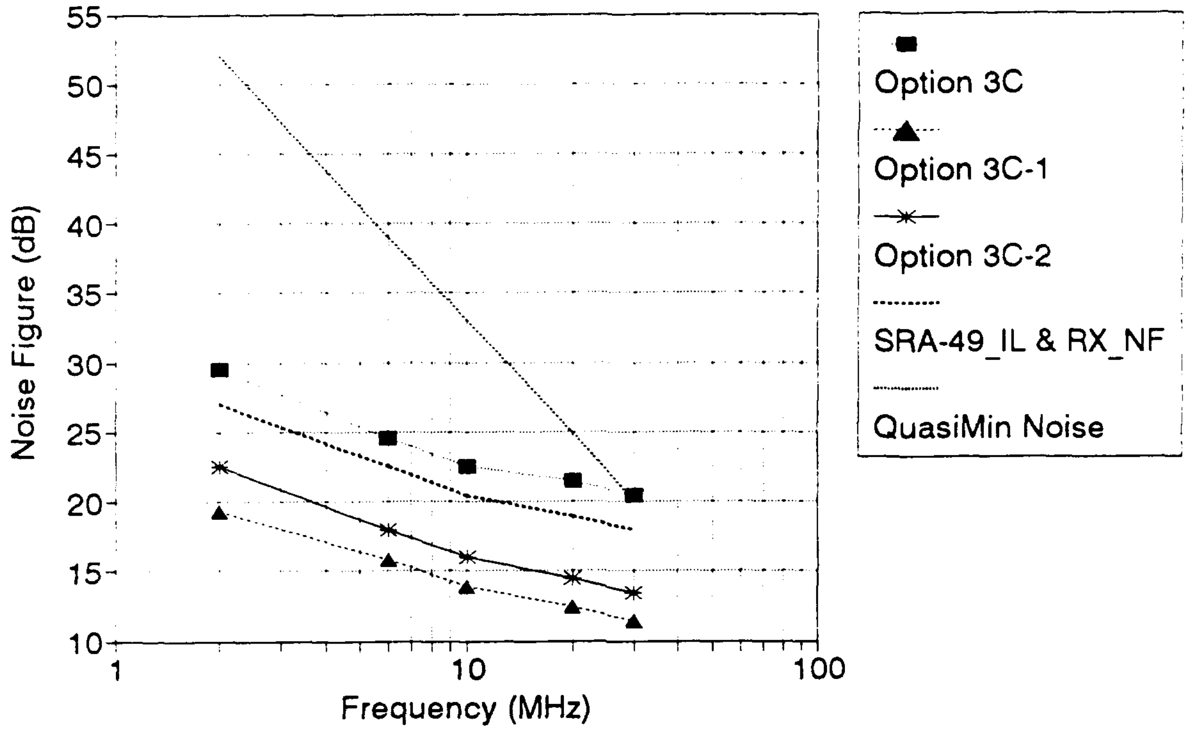

Figure 39. Option 3C noise figures with preamp gain = 20 dB.

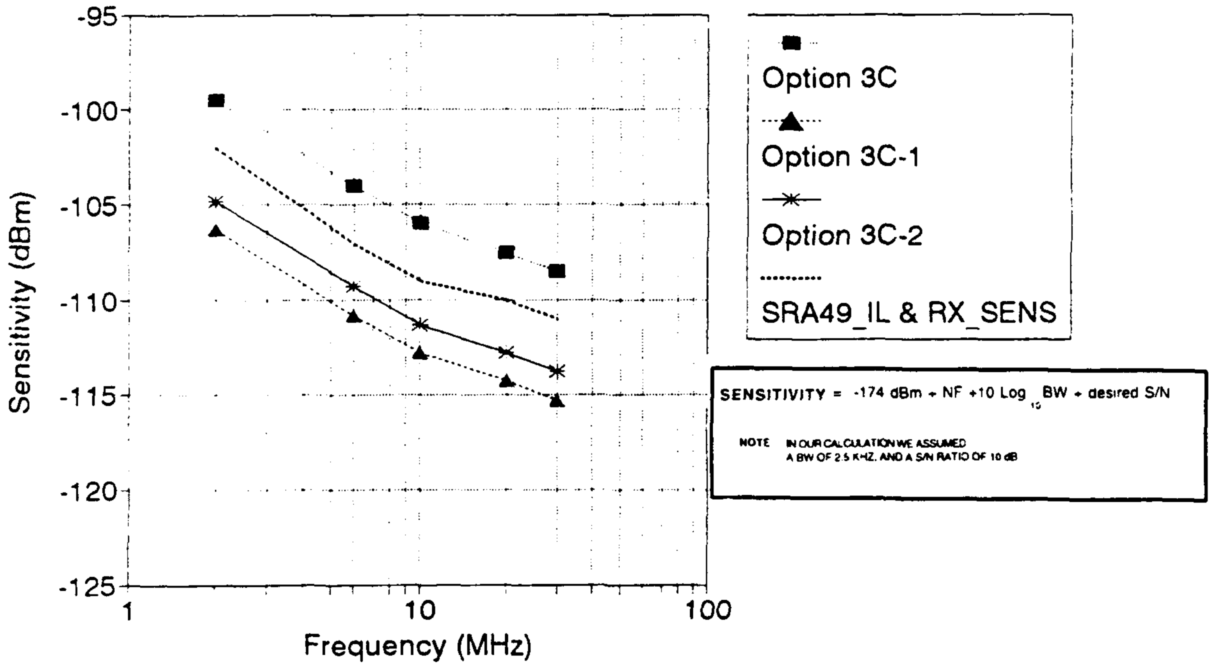

Figure 40. Option 3C sensitivity plot with preamp gain = 10 dB.

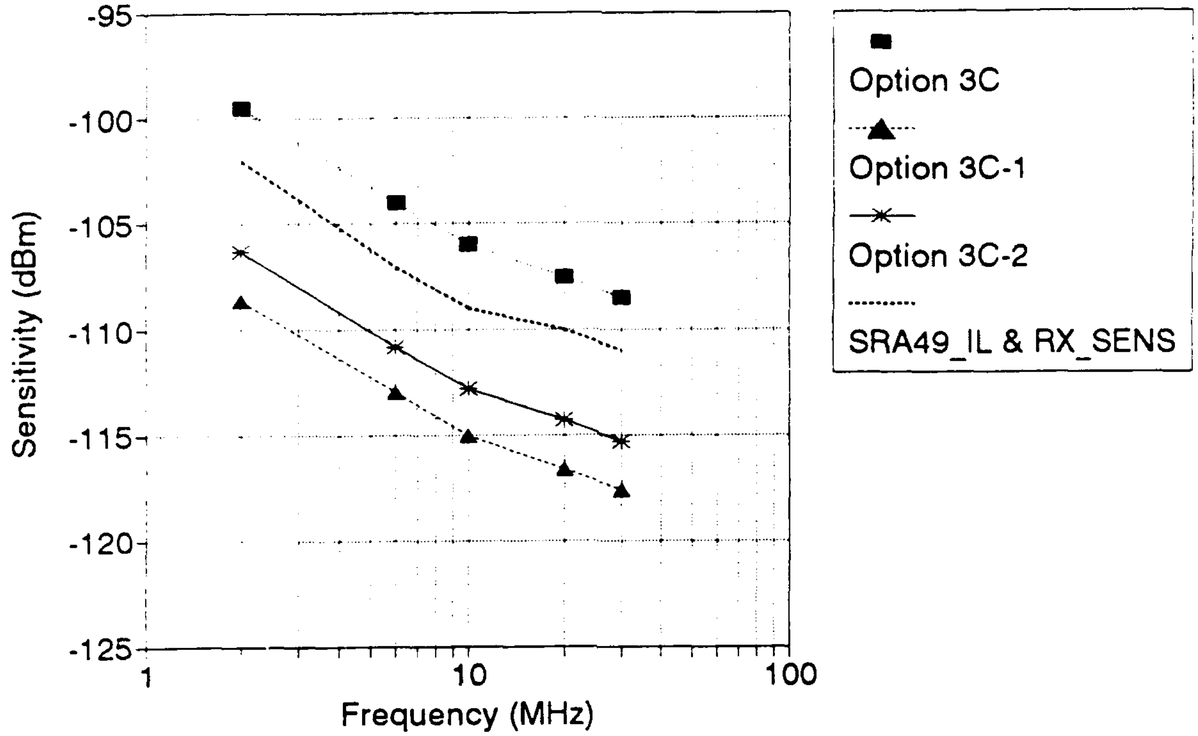

Figure 41. Option 3C sensitivity plot with preamp gain = 20 dB.

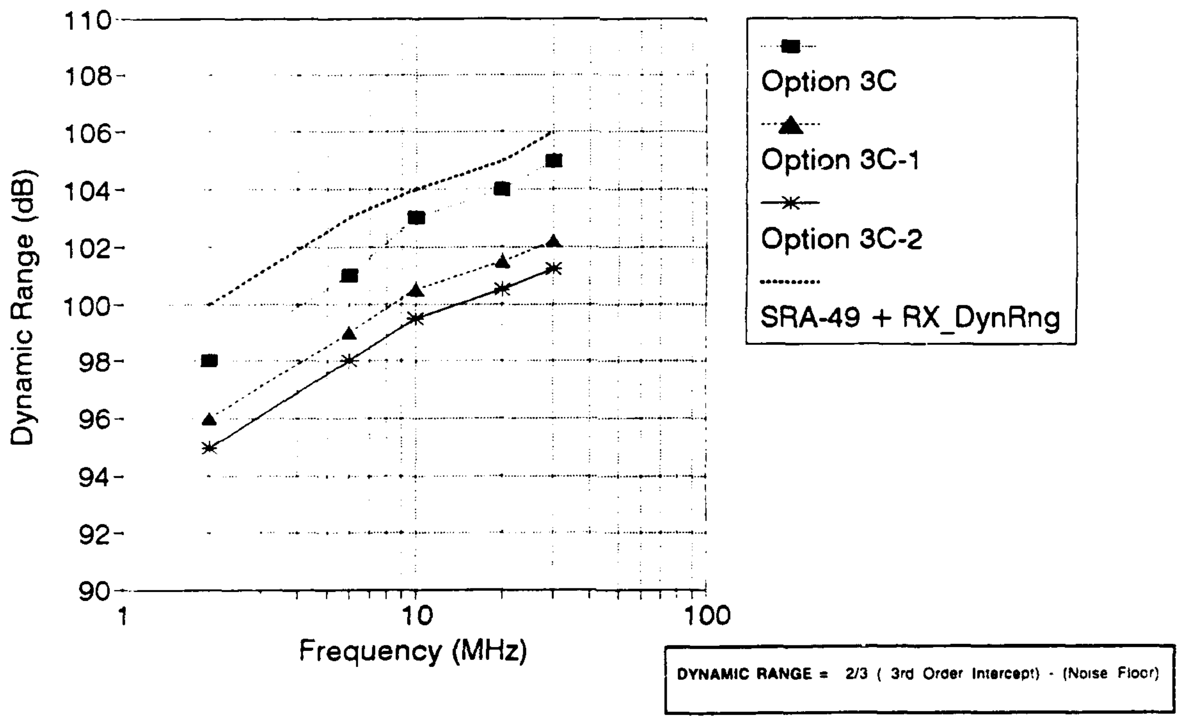

Figure 42. Option 3C dynamic range plot with preamp gain = 10 dB.

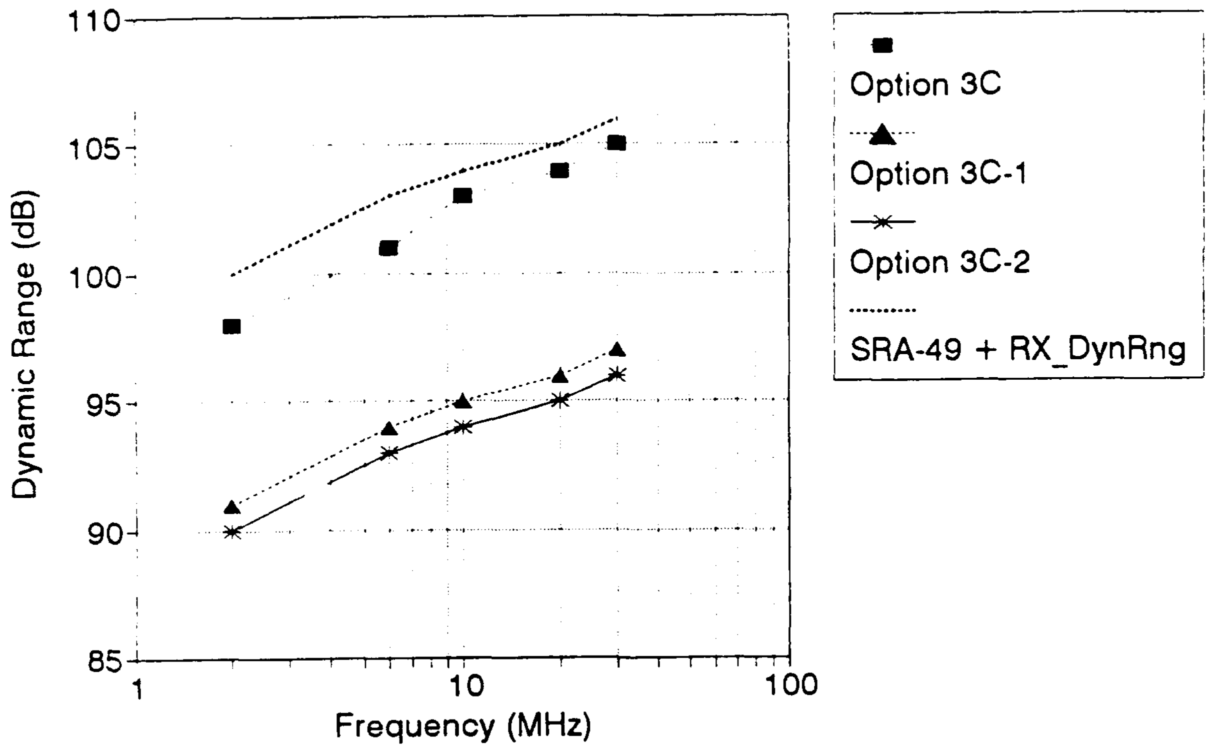

Figure 43. Option 3C dynamic range plot with preamp gain = 20 dB.

Table 14. Noise figure calculations for option 3C (preamp G = 20 dB).

FREQ (MHz)	OPTION 3C **NF** (dB)	OPTION 3C-1 **NF** (dB)	OPTION 3C-2 **NF** (dB)	SRA-49 **IL** (dB)	QminNOISE (dB)
2.0	29.5	19.4	22.5	15.0	52.0
6.0	24.5	15.9	18.0	10.5	39.0
10.0	22.5	13.9	16.0	8.5	33.0
20.0	21.5	12.4	14.5	7.0	24.0
30.0	20.5	11.4	13.5	6.0	20.0

Table 15. Noise figure calculations for option 3C (preamp G = 10 dB).

FREQ (MHz)	OPTION 3C **NF** (dB)	OPTION 3C-1 **NF** (dB)	OPTION 3C-2 **NF** (dB)	SRA-49 **IL** (dB)	QminNOISE (dB)
2.0	29.5	22.7	24.2	15.0	52.0
6.0	24.5	18.2	19.7	10.5	39.0
10.0	22.5	16.2	17.7	8.5	33.0
20.0	21.5	14.7	16.2	7.0	24.0
30.0	20.5	13.7	15.2	6.0	20.0

Table 16. Option 3C-1 system tradeoff considerations.

AT FREQ = 2 MHz	OPTION 3C	**OPTION 3C-1** W/ 20 dB GAIN PREAMPLIFIER	**OPTION 3C-1** W/ 10 dB GAIN PREAMPLIFIER
Noise (dB)	29.5	19.4	22.7
Sensitivity (dBm)	–99.5	–108.6	–106.3
3Rd Order I.P. (dBm)	+48.0	+28	+38
Dynamic Range (dB)	98	91	96

Table 17. Option 3C-2 system tradeoff considerations.

AT FREQ = 2 MHz	OPTION 3C	**OPTION 3C-1** W/ 20 dB GAIN PREAMPLIFIER	**OPTION 3C-1** W/ 10 dB GAIN PREAMPLIFIER
Noise (dB)	29.5	22.8	24.2
Sensitivity (dBm)	–99.5	–106.3	–104.8
3Rd Order I.P. (dBm)	+48.0	+28	+38
Dynamic Range (dB)	98	90	95

Table 18. Option 3C cost comparisons.

OPTION 3C	DIVIDERS	$1,440
– 20 POWER DIVIDERS	COMBINERS	$590
– 3 POWER COMBINERS	TOTAL	**$2,030**

OPTION 3C-1	PREAMPLIFIERS	$16,000
– 20 PREAMPLIFIERS	DIVIDERS	$1,440
– 20 POWER DIVIDERS	COMBINERS	$590
– 3 POWER COMBINERS	TOTAL	**$18,030**

OPTION 3C-2	PREAMPLIFIER	$800
– PREAMPLIFIER	DIVIDERS	$1,440
– 20 POWER DIVIDERS	COMBINERS	$590
– 3 POWER COMBINERS	TOTAL	**$2,830**

(See table 20)

Table 19. Components specifications/costs.

RF AMPLIFIER	POWER DIVIDERS/COMBINERS
MANUFACTURER: Aiken Advance System MODEL NO. **AMP–1200** $800 ea.	MANUFACTURER: OLEKTRON Corp. MODEL NO. **HJ–22001** $72 ea. MODEL NO. **HJ–44001** $105 ea. MODEL NO. **HJ–28001** $315 ea.
SPECIFICATIONS	**SPECIFICATIONS**
FREQ. RANGE: 1.5 to 32 MHz	FREQ. RANGE: 1.5 to 32 MHz
GAIN: 12 to 21 dB	INSERTION LOSS: 0.5 to 1.75 dB (max)
NOISE FIGURE: 5.0 dB (typical)	

RF SWITCH	HF RECEIVE ANTENNA COUPLER
MANUFACTURER: M/A-COM MODEL NO. **652** $9,900 ea.	MANUFACTURER: Aiken Advance Sys. MODEL NO. **CU–2289** $5,720 ea.
SPECIFICATIONS	**SPECIFICATIONS**
FREQ. RANGE: DC to 500 MHz	FREQ. RANGE: 1.5 to 32 MHz
INSERTION LOSS: 3 dB (typical)	GAIN: 0 ± 2 dB
	NOISE FIGURE: 12.0 dB (max)

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13. ABSTRACT *(Maximum 200 words)*

The scope of the task reported here was to develop implementation techniques and concepts of operation for using HF ALE techniques, as presented in MIL-STD-188-141A, with shipboard systems designed to quickly establish good, reliable ship/beach and ship/ship communications (links and networks) for effective use by any control method/system.

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